Hardwood Nutrition

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EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZATION ON GROWTH OF A SWEETGUM PLANTATION DAMAGED BY AN ICE STORM

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Abstract—In 1994, an ice storm impacted a 19-year-old sweetgum plantation (*Liquidambar styraciflua* L.) fertilized with nitrogen (N) and phosphorus (P) at age 4. Thirty-nine percent of the stems were broken, 55 percent were not damaged, and 6 percent were leaning. After the ice storm, differences in height and dbh among the fertilization treatments disappeared. To test if fertilization can increase growth of both damaged and undamaged trees, we applied N and P fertilizers in early 1999. Two fertilizers, ammonia nitrate and superphosphate, were used in four combinations of treatments: N only (205 lb. N/ac), P only (123 lb. P/ac), N+P (205 lb. N/ac + 123 lb. P/ac), and a control. The treatments were on the same plots that were treated at age 4. After one growing season, N increased overall dbh growth, and P increased height growth. The effect of P was mostly on the damaged trees with height growths of 5.8 feet for P only, and 6.5 feet for the N+P treatment, compared to 4.8 and 5.1 feet for N only and the control, respectively. P had been shown to increase height growth with N at age 11.

INTRODUCTION

Sweetgum (*Liquidambar styraciflua* L.) was one of the hardwood species that was used to meet demand for fiber in the 1970s. Fertilization was used to increase sweetgum productivity on less fertile sites, such as Coastal Plain soils. This study was established in 1975 to test the effect of nitrogen (N) and phosphorus (P) fertilization on growth of sweetgum seedlings. After one growing season, N fertilization increased both total height and diameter of the 4-year-old plantation (Ku and others 1981). The gain in height and diameter was maintained for many years. When last reported (Guo and others 1998), the 15-year-old trees treated with N fertilization averaged about 5.5 inches in dbh, which was significantly greater than those without N fertilization. Height was also greater for the trees treated with N only, but N+P fertilization further increased height growth at age 14. The effect of N on sweetgum growth has been previously studied in the southern United States (Berry 1987, Broadfoot 1966, Buckner and Maki 1977, Ku and others 1981, Nelson and Switzer 1990, Nelson and others 1995a). These studies revealed that fertilization, especially with N, improved sweetgum growth on soils ranging from fertile alluvial soils to less fertile Coastal Plain soils. Significant growth improvement with fertilization even occurred in a 20-year-old sweetgum stand (Broadfoot 1966). As for P fertilization, Nelson and Switzer (1990) found in a preliminary greenhouse study that sweetgum responded to P fertilization, but that P did not increase growth in a field study. Broadfoot (1966) reported greater height growth of a 20-year-old sweetgum following a N+P+potassium (K) application.

On February 10, 1994, an ice storm struck southeastern Arkansas and caused considerable damage to the sweetgum plantation. Overall, trees with stem breakage averaged 39 percent, compared to 55 percent with no damage, and 6 percent leaning. Percentage of breakage did not differ statistically among fertilization treatments (Guo 1999). After the ice storm, differences in height and dbh among the fertilization treatments disappeared. To test whether fertilization can increase growth of both damaged and undamaged trees, we applied fertilizers to the plantation. The objective was to determine the effect of N and P fertilization on height and dbh growth of damaged and undamaged 25-year-old sweetgum trees.

METHODS AND PROCEDURES

The study was located in Drew County, AR (91° 46' W and 33° 37' 31" N) in the West Gulf Coastal Plain physiographic province. The soil is a poorly-drained Henry silt loam (Typic Fragiaqualf) and was formed from wind-blown silt. The native vegetation is mixed pines and hardwoods. A representative soil profile includes a surface 28-in. thick, light-gray to gray mottled silt loam, a 25-in. thick subsoil of firm, brittle fragipan (light-brownish gray, mottled silt clay loam), and mottled silt loam beneath to a depth of 72 inches. The natural fertility is moderate and the site index for sweetgum is 80 feet at age 50 (Larance and others 1976). The climate is subtropical humid with an average annual rainfall of 53 inches per year. Rainfall is somewhat greater in the winter and early spring, and summers may include drought periods.

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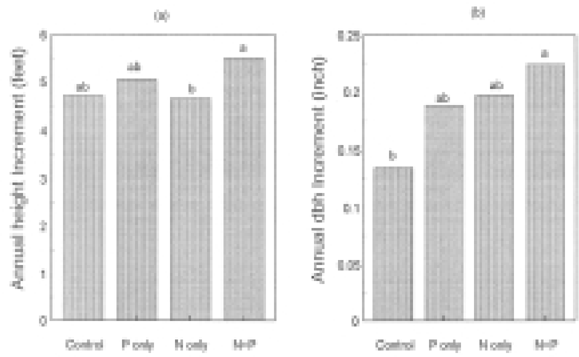

Figure 1—Effect of nitrogen and phosphorus fertilization on overall height (a) and dbh (b) increments one growing season after fertilization. Bars with the same letter are not significantly different at $\alpha = 0.05$.

The study was established in 1975 with 1-year-old seedlings (1-0 stock) planted at a spacing of 9 x 9 feet. Two fertilizers, ammonium nitrate and superphosphate, were applied in 1979 with an experimental design of 2 x 2 factorial in a completely randomized block layout with six blocks. The four combinations of treatments were N only at a rate of 205 lb. N/ac of ammonium nitrate (N only), P only at 123 lb. P/ac of superphosphate (P only), N and P at 205 lb. N/ac + 123 lb. P/ac (N+P), and no N or P [control (C)]. Each plot contained 50 trees (537 trees/ac), with 10 trees in each of five rows. The first and last row and the first tree and last tree of each row served as border trees to isolate the effects of adjacent plots. Measurements were obtained from the interior 24 trees. The survival rate was from 62 to 73 percent at age 15, but did not differ significantly among treatments. The ice storm did not affect the survival. In the spring of 1999, five growing seasons after the ice storm, plots were treated with the same rates of N and P that were used in 1979. Granular fertilizers were applied on the soil surface by hand. Height and dbh were measured just before the fertilization. Total height and dbh did not differ significantly prior to the treatments. After one growing season of fertilization, height and dbh were measured in January 2000.

Annual increments in height and dbh were analyzed by General Linear Models of SAS (SAS Institute, Inc., 1990). The data analysis was based on a split plot model with fertilization as the major plot and ice damage as the subplot. The subplot had two levels: damaged and undamaged. Leaning trees were considered undamaged trees. A small number of damaged trees (< 4percent on average per plot) did not show any growth, so these trees were not included in the data analysis. Means were separated by the Ryan-Einot-Gabriel-Welsch multiple range test at $\alpha = 0.05$.

RESULTS

Overall, P influenced height increments at $p = 0.09$, and N affected dbh increments at $p = 0.08$. There was no interaction between N and P ($p = 0.81$ for height and $p = 0.56$ for dbh). Height increments averaged 5.5 feet for the N+P treatment and 5.1 feet for the P only treatment, which were significantly greater than the 4.7 feet for the N only treatment. However, height increments for the N+P and P only treatments did not differ statistically from the control, while height increments among the P only, N only, and the control were not significantly different (figure 1a). For the dbh increment, N+P fertilization resulted in a growth of 0.22 inches, which was not statistically different from 0.20 inches for the N only and 0.19 inches for the P only treatments but significantly greater than the 0.14 inches for the control. (figure 1b).

Height growth of the damaged trees was significantly greater than the undamaged trees. Damaged trees

Table 1—Mean annual height and diameter increments of damaged and undamaged trees and their associated standard errors of an ice-storm damaged sweetgum plantation one growing season after fertilization with nitrogen and phosphorus

	Damaged		Undamaged	
Treatment	Mean	Standard Error	Mean	Standard Error
	------------------------*Height Increment (feet)*------------------------			
Control	5.07	0.37	4.35	0.40
P only	5.81	0.32	4.31	0.49
N only	4.76	0.42	4.55	0.38
N+P	6.47	0.44	4.55	0.37
	------------------------*Dbh Increment (inch)*--------------------------			
Control	0.08	0.08	0.20	0.08
P only	0.14	0.12	0.23	0.13
N only	0.16	0.11	0.23	0.15
N+P	0.18	0.09	0.27	0.15

averaged 5.5 feet during the growing season after the fertilization while undamaged trees averaged 4.4 feet. Dbh growth was opposite. Dbh growth was 0.23 inches for the undamaged trees, which was significantly greater than the 0.14 inches growth for the damaged trees.

The difference in height growth among the treatments was likely caused by the effect of the P fertilization on damaged trees (table 1). The height increments were 5.81 and 6.47 feet for the P only and N+P treatments, respectively, which were greater than those (5.07 and 4.76 feet) for the control and N only treatments. Height growth of the undamaged trees was similar among the treatments. The pattern of the dbh increments among the treatments for the damaged trees was similar to that of the overall increments, except that dbh increments were smaller for the damaged trees than the overall means (table 1).

DISCUSSION

N fertilization did not affect height growth of both damaged and undamaged trees, but P affected height growth in this study. Broadfoot (1966) found height increases for a 22-year-old sweetgum stand fertilized with N+P+K. However, it was not clear whether N alone increased the height growth in the study. P was not found to increase height growth in other studies for young stands (Berry 1987, Buckner and Maki 1977, Nelson and others 1995a), including the stand of this study in early ages. However, at age 14, P along with N was found to increase height growth significantly (Guo and others 1998). This phenomenon probably resulted from an increased demand of P by the faster-growing trees. P did not affect height growth of the young sweetgum stands because demand for P was relatively low. As demand of large trees increased, especially the trees with greater height, additional P in the soil promoted height growth. It seems that accelerated height growth of larger trees requires more P to maintain the increased height growth rates, this seems evident from the results of Broadfoot (1966), Guo and others (1998), and this current study.

The response of height growth to P in this study was complicated by the ice storm damage. Since the ice storm, height growth of the damaged trees has been significantly greater than that of the undamaged trees, although there have been no significant differences among the fertilization treatments. Increased height growth of ice storm damaged trees was also observed by Dunham and Bourgeois (1996). They attributed this phenomenon to the fact that most damaged trees were initially dominant or codominant trees, and rapid height growth was to recapture the lost crown position. The sweetgum trees in this study acted similarly to those of Dunham and Bourgeois (1996). Since larger sweetgum trees, compared to surrounding trees, have a greater probability to be broken (Guo 1999), most damaged trees were dominant and codominant trees. Compared to the damaged trees, undamaged trees had greater dbh growth but relatively slower height growth, although the height growth was also fairly fast (> 4 feet during the growing season of 1999, which was faster than a 3-foot average height growth for sweetgum). It seems that P further increased height growth of the damaged trees because they needed greater height growth to recapture their crown positions. This demand required additional P from the soils. Without the additional P, height growth potential was limited.

A related phenomenon to the greater height growth of the damaged trees was their reduced dbh growth compared to the undamaged trees. It seems that P does not affect dbh growth of sweetgum and N is more important than P for dbh growth. With accelerated height growth, the damaged trees had to allocate more resources for height growth. Dbh growth was then slowed.

Overall, the average heights of the undamaged and damaged trees were 57.8 and 50.2 feet, respectively, at age 25. The site index for the undamaged trees was slightly greater than the 80-foot site index at age 50, which is about 55 feet at age 25, based on the site index curves developed by Clatterbuck (1987) for central Mississippi minor bottoms. This site index of the undamaged trees is greater than that measured two years after the ice storm or three years before this measurement. The site index of the undamaged trees was below 80 feet at age 50 then. Three years later, site indexes have increased to about 85 feet. This phenomenon suggests that the undamaged trees have been growing faster after the ice storm than before it. The ice storm resulted in the undamaged trees switching from being less dominant to dominant or codominant trees, and they have been growing with a faster-than-average height growth rate in the last five years. On the other hand, although the damaged trees have been growing faster than the undamaged trees in height, they still have an additional 7-8 feet to grow before they catch up.

CONCLUSION

Phosphorus fertilization at age 24 increased overall height growth of the sweetgum plantation, but the effect was mostly on the damaged trees. Nitrogen fertilization helped dbh growth, but not the height growth. Damaged trees had greater height growth but smaller dbh growth than the undamaged trees.

REFERENCES

Berry, C.R. 1987. Use of municipal sewage sludge for improvement of forest sites in the southeast. Asheville, NC: U.S. Department of Agriculture, Forest Service Res. Pap. SE-266, Southeastern Forest Experiment Station. 33 p.

Broadfoot, W.M. 1966. Five years of nitrogen fertilization in a sweetgum-oak stand. USDA Forest Service Research Note SO-34. 3 p.

Buckner, E.; T.E. Maki. 1977. Seven-year growth of fertilized and irrigated yellow poplar, sweetgum, northern red oak, and loblolly pine planted on two sites. Forest Science. 23: 402-410.

Clatterbuck, W.K. 1987. Height growth and site index curves for cherrybark oak and sweetgum in mixed, even-aged stands on the minor bottoms of central Mississippi. Southern Journal of Applied Forestry 11(4): 219-222.

Dunham, P. H.; D. M. Bourgeois. 1996. Long-term recovery of plantation-grown loblolly pine from hurricane damage. In: J. L. Haymond and W. R. Harms. Eds. 1996. Hurricane Hugo: South Carolina forested land research and management related to the storm. Gen. Tech. Rep. SRS-5. Asheville, NC. U.S.Department of Agriculture, Forest Service. 480-490 p.

Guo, Y. 1999. Ice storm damage to a sweetgum plantation fertilized with nitrogen and phosphorus. Southern Journal of Applied Forestry. 23(4): 224-229.

Guo, Y.; T. Ku; B. Lockhart. 1998. Effect of nitrogen and phosphorus fertilization on growth in a sweetgum plantation in southeastern Arkansas. Southern. Journal of Applied Forestry. 22(3): 163-168.

Ku, T.T.; J.K. Francis; C.R. Blinn. 1981. Fertilizer response and biomass accumulation of a five-year-old sweetgum plantation. In: Barnett, J.P., ed. Proceedings of the First biennial southern silvicultural research conference; 1980 November 6-7, Atlanta, GA. Gen. Tech. Rep. SO-34. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 195-198.

Larance, F.; H.V. Gill; C.L. Fultz. 1976. Soil survey of Drew County, Arkansas. U.S. Department of Agriculture Soil Conservation Service. 86 p.

Nelson, L.E.; M.G. Shelton; G.L. Switzer. 1995a. Aboveground net primary productivity and nutrient content of fertilized plantation sweetgum. Soil Science Society American Journal. 59: 925-932.

Nelson, L.E.; G.L. Switzer. 1990. Sweetgum half-sib seed source response to nitrogen and phosphorus fertilization in Mississippi. Soil Science Society American Journal. 54: 871-878.

SAS Institute, Inc., 1990. SAS User's Guide, Version 6, 4th Edition. SAS Institute, Inc., Vol. 2. Cary, NC. 846 p.

SWEETGUM RESPONSE TO NITROGEN FERTILIZATION ON SITES OF DIFFERENT QUALITY AND LAND USE HISTORY

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Abstract—Nitrogen (N) fertilizer management in young hardwood plantations is difficult due to our lack of understanding of the site-specific mechanisms that control tree response. Differences in landuse history and soil characteristics can alter the plant response to added N considerably. Foliage biomass, N content, N concentration, resorption, and soil N supply characteristics were measured on two 4 year-old sweetgum (*Liquidambar styraciflua* L.) plantations in South Carolina that represent different landuse histories and soil types. Fertilizer responses were much greater overall on a poorly drained pine cutover site compared to a well-drained ag field. Vector analysis and analysis of variance indicated that fertilization increased foliage biomass, N content, N concentration, and leaf area on the cutover site, but only increased foliar N content on the ag site. Foliar responses were negatively related to actual soil N supply, but not potentially mineralizable or total N. N fertilizer recommendations must be site-specific, and an accurate estimate of soil N supply is essential for increasing fertilization efficiency.

INTRODUCTION

Sweetgum and other hardwood plantations have the potential to be an important source of hardwood fiber throughout the South, but the success of hardwood plantations depends heavily on management intensity. Relative to loblolly pine plantations, sweetgum plantations require more intensive site selection and preparation, herbaceous and woody competition control, and nutrient management for plantation success.

Abandoned or marginal agricultural fields have historically been the primary lands planted to hardwood plantations throughout the South, but the demand and value of hardwood fiber coupled with the relative paucity of agricultural lands in certain local areas has increased the area of cutover pine lands planted to hardwood plantations. Within these two groupings of potential hardwood plantation lands, wide differences exist in soil types, which makes our understanding of site-specific plantation responses to various treatments difficult.

Specifically, accurate, site-specific hardwood nitrogen (N) fertilizer recommendations are not yet available for hardwood plantations because of our lack of understanding of the site-specific influences on soil N supply, plant N demand, and plant response to various fertilizer rates. Several studies have shown the impressive response of young hardwood stands to N fertilizer, but variations in soil types, fertilizer rates, and management differences have hindered our ability to make accurate N fertilizer recommendations.

In most studies, N fertilization has resulted in growth responses. A few studies have linked N fertilization response to soil type or previous management (Torreano and Frederick, 1988), illustrating that the soil N supply can control the response to added N. For example, Wittwer and others (1980) applied N fertilizer each year to sycamore (*Platanus occidentalis* L.) on a bottomland site and on a terrace site. They observed a 45 percent growth response on the bottomland site and a 205 percent growth response on the terrace site at age 5, and attributed the relative response to soil N. Torreano and Frederick (1988) and Blackmon (1977) showed that hardwoods may respond quite differently on pine cutover sites than on abandoned agricultural sites.

Most recently, studies have focused on determining fertilization effects on specific plant responses other than height or volume growth. Since approximately 50 percent of aboveground plant N uptake is met by resorption of foliar N prior to senescence (Aerts and Chapin, 2000), factors which affect the resorption efficiency may dramatically change fertilizer needs. Nelson and others (1995) reported resorption efficiencies of 50-74 percent for sweetgum and attributed differences to environmental conditions, i.e., moisture availability, but not N fertilization. Kuers and Steinbeck (1998a) found similar efficiencies of 43-62 percent for sweetgum, but reported significant increases in resorption efficiency in the fertilized treatment.

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To better understand the processes controlling sweetgum response to added N, the objectives of this study were to quantify the foliar response to N fertilizer treatments on two contrasting site types and relate potential differences in foliar responses to soil N supply parameters.

METHODS

Site Descriptions and Characterization

The pine cutover site is on Westvaco Corporation land, located in Colleton County, South Carolina (32° 8' N 80° 7' W) on the lower Atlantic coastal plain, and was established in February 1995. The soil is a somewhat poorly to poorly drained Argent sandy loam (clayey, mixed, active, Typic Endoaqualfs) developed from marine deposits. The site undergoes wide fluctuations in soil water contents, from saturated soils with standing water in the bed furrows in the late fall until spring to dry soils during the growing season. Nine 0.2 ha sweetgum plots were established following loblolly pine harvest and site preparation, which consisted of bedding, fertilization and non-crop vegetation control. All plots received 280 kg/ha diammonium phosphate (DAP) in March 1995. Non-crop vegetation control consisted of pre-emergent herbicide applications in February and March of 1995, 1996, and 1997. Herbicides were also applied by directed spray in 1995 and 1996 during the growing season.

The agricultural field study site is located on International Paper's Trice Research Forest in Sumter County, South Carolina (33° 58' N 80° 12' W) on the middle Atlantic coastal plain. The soil is a well-drained Norfolk sandy loam (loamy, kaolinitic, thermic Typic Kandiudult. Nine 0.2 ha sweetgum plots were established in 1996. The sites had been regularly managed for dryland crops (corn, soybeans, etc.) for more than 20 years, and soybeans (*Glycine max.* (L.) Merr) were the primary crop for the 5 years previous to woody crop plantation conversion. All plots were treated with an initial fertilizer program of 280 kg/ha diammonium phosphate (DAP) in November 1995 and 101 kg/ha urea in August 1996.

Experimental Design

At each site, three biannual N fertilizer treatments were initiated at age 1 and replicated three times. Every two years, ammonium nitrate (NH^4NO^3) was applied at the following rates: 0 kg/ha, 168 kg/ha, and 336 kg/ha, which provide 0, 56, and 112 kg/ha N, respectively. The error control design at the cutover site was a Completely Randomized Design, while the design at the agricultural site was a Randomized Complete Block Design. The blocking factor was depth to mottling.

Table 1—Proportion of total foliage dry mass in each of three crown positions by fertilizer treatment, after Kuers and Steinbeck, 1998b

Crown	Control	Low N	High N
Upper	0.35	0.35	0.35
Middle	0.38	0.41	0.44
Crown	0.27	0.24	0.21

Foliage Measurements

In September 1998 (pine cutover site) and 1999 (ag field), which corresponded to age 4 in both plantations, 3 foliage samples were taken from the southern portion of the canopy from five trees in each plot. Upper, middle, and lower crown samples comprised of leaves of all stages of development were collected from single branches within the respective crown position (Kuers and Steinbeck, 1998b). The leaves were refrigerated until leaf area determinations were made with a Li-Cor Leaf Area Meter (Li-Cor, Lincoln, NE). The leaves were then oven dried at 65 °C for at least 72 hours and weighed to determine specific leaf area (cm^2/g). Foliar N concentration was determined on each sample with a N analyzer (LECO FP-528, St. Joseph, MI) and converted to total nutrient content with estimates of foliage mass obtained from litterfall measurements. Litterfall was collected from 5 randomly located litter traps (approximately 1 m^2 per trap) per plot.

Kuers and Steinbeck (1998b) showed that fertilization increases sweetgum leaf area disproportionately between the leader, upper, middle, and lower crown positions. If the leader is included with the upper crown, they found 35, 37, and 27 percent of the total dry mass in the upper, middle, and lower crowns positions, respectively. However, in plots fertilized at a higher rate of N than the highest rate in this proposed study, they found 36, 44, and 21 percent of total dry mass in the upper, middle, and lower crown positions, respectively. We calculated total foliar nutrient demand as the summation of the products of foliar nutrient concentration and estimated foliage mass for each crown position (table 1). Foliar N resorption was calculated as the difference between foliar N content at midseason and in the litterfall (Nelson and others, 1995).

Soil Nitrogen Supply

Total nitrogen—Total N was determined on a 5 g soil sample using the macro-Kjeldahl digestion method (Bremner and Mulvaney, 1982) followed by colorimetric analysis (Bran+Luebbe TRAACS 2000, Oak Park, IL).

Potentially mineralizable nitrogen—Nitrogen mineralization potential was determined by measuring NH^{4+} and NO^{3-} produced in biweekly extractions of aerobically incubated soil samples for 24 weeks (Stanford and Smith, 1972; Burger and Pritchett, 1984). Briefly, approximately 70 g field-moist soil from each site was mixed with approximately 150 g washed silica sand and lightly packed into a 5 cm i.d. and 15 cm long PVC tube. The samples were incubated at 35 °C. Every two weeks, the samples were leached with 250 mL of 0.01 M CaCl2, which was analyzed for NH^{4+} and NO^{3-} concentration via automatic colorimetric spectrophotometry on a TRAACS 2000 (Bran & Luebbe Corporation, Oak Park, IL). The samples were then leached with 100 mL of a minus-N Hoagland solution and vacuum extracted to approximately -0.03 MPa (field capacity). N mineralization potential was calculated by fitting a first-order curve to the sequential N produced using PROC NLIN in SAS (SAS, 1990).

Table 2— Foliar biomass, weighted foliar N concentration and litter N concentration for two 4-year-old sweetgum plantations of different landuse history and soil type. Means within a site followed by the same letter are not significantly different at alpha=0.10

Treatment	Foliar Biomass kg/ha	Foliar N Concentration pct	Litter N Concentration pct
Ag field			
Control	2263a	1.37a	0.97a
56 kg/ha N	2475a	1.71a	0.97a
112 kg/ha N	3100a	1.69a	1.00a
Pine cutover			
Control	1337b	1.14c	0.63b
56 kg/ha N	1945ab	1.39b	0.73ab
112 kg/ha N	2825a	1.54a	0.76a

***In situ* nitrogen production—**Native soil N supply was measured from April 1999 to April 2000 with the buried bag method (Eno, 1960). For this procedure, two soil samples were collected for each sampling date. One was incubated in situ and the other returned to the laboratory for analysis. N supply was calculated as the difference between the N intensity in the soils incubated for approximately 1 month and the samples taken at the time of incubation, with negative values, representing net immobilization or denitrification, set to 0. At each of three subplots within each experimental plot, three subsamples were taken of the top 15 cm and composited for each of the two samples (bags). Each sample was air-dried, sieved to pass a 2 mm sieve, and the N extracted with 2 N KCl in a 10:1 solution:soil ratio. The NH4+ and NO3- concentration in each extract was determined via automatic colorimetric spectrophotometry on a TRAACS 2000 (Bran & Luebbe Corporation, Oak Park, IL).

Soil moisture—Volumetric soil moisture in the top 15 cm was measured monthly from April 1999 to September 2000 with Time Domain Reflectometry.

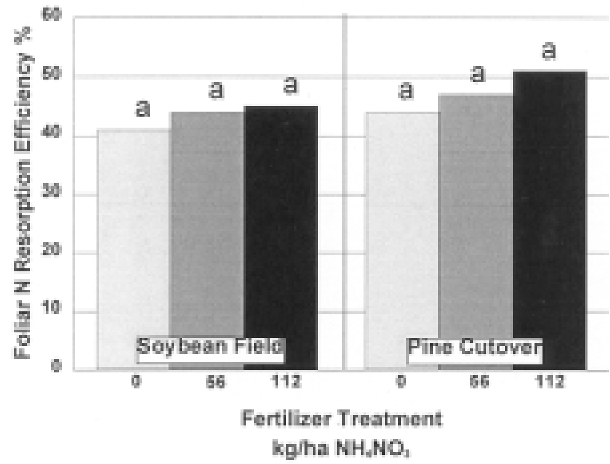

Figure 2—Foliar nitrogen resorption efficiency across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

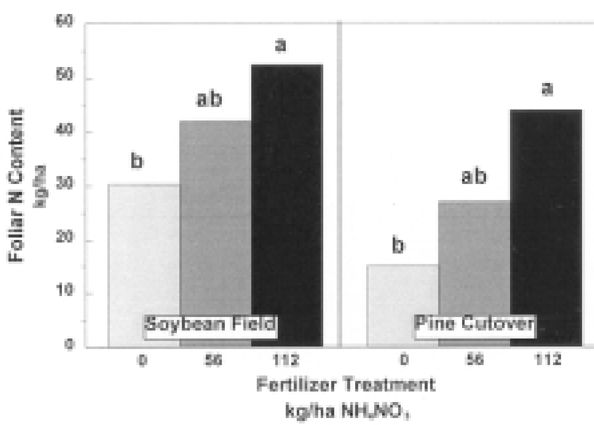

Figure 1—Foliar nitrogen content across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

RESULTS

Fertilization increased foliar biomass, N concentration, and N content at both sites, but the relative responses were greater on the pine cutover site. Foliar N content increased at both sites on fertilized plots (figure 1) due to increases in total foliage biomass and N concentrations (table 2). On the ag field, foliar N content of the 56 kg/ha N treatment was 40 percent higher than the control, while it was 73 percent higher than the control in the 112 kg/ha N treatment. In the cutover pine site, foliar N content increased 80 percent and 193 percent over the control in the medium and high treatments, respectively. Weighted foliar N concentrations ranged from 1.14 percent to 1.71 percent, and increased at both sites with fertilization.

Foliar resorption efficiency, which is calculated as the proportion of total foliar N resorbed, was not different among fertilization treatments, and the pine cutover site had greater resorption efficiency compared to the ag field site (figure 2). Foliar resorption proficiency, which is measured as the N concentration in the litterfall, was not

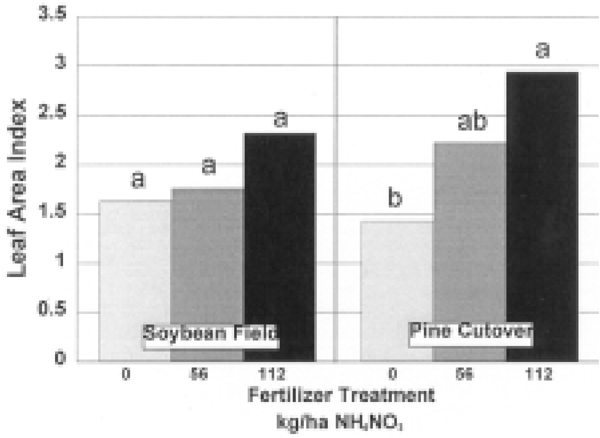

Figure 3—Leaf area index across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

affected by fertilization treatment at the ag field site. In the pine cutover site, resorption proficiency was greater than in the ag field site (litter N concentrations lower), and was significantly reduced (litter N concentrations higher) by the highest fertilization rate (table 2).

Leaf area index of trees on the ag field ranged from 1.6 to 2.3, but was not significantly affected by fertilization. LAI of the 112 kg/ha N treatment (3.0) was twice that of the control (1.5) in at the pine cutover site (figure 3). Plot volume index (PVI) did not differ among treatments on the ag field site (figure 4), and although not significantly different, PVI was 47 and 63 percent higher than the control in the 56 kg/ha and 112 kg/ha N treatments, respectively on the pine cutover site.

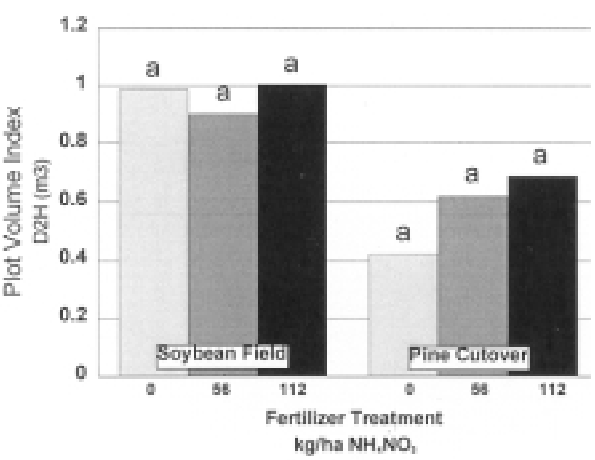

Figure 4—Plot volume index across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

Soil nitrogen differed widely between the sites and among indices (figure 5). Total soil N in the top 15 cm of the cutover pine site was 2.6 times higher than that of the ag field site, but the aerobic index of potentially mineralizable N was only 18 percent higher. Measured in situ N production was much less in the cutover pine site, averaging 72 percent less than in the ag field site.

Soil moisture varied seasonally and across both sites, but was consistently greater on the poorly-drained cutover site compared to the well-drained ag site (figure 6). Soil moisture averaged 9.7 percent on the ag site and was never greater than 20 percent, while soil moisture averaged 19.9 percent on the cutover site and was as high as 32 percent.

DISCUSSION

Foliar biomass production, N demand, and N resorption were each associated with site type and fertilizer treatments. Foliage production ranged from 1337 kg/ha to 3100 kg/ha, and foliar N content ranged from 15 to 53 kg/ha. Higher foliage biomass production, however, did not directly result in higher leaf areas (figure 3) nor tree growth (figure 4) in these young stands, but may in the future. Foliage production and foliar N content was greater overall at the ag field site compared to the pine cutover site, but fertilization responses were more dramatic on the cutover site. A host of factors may have contributed to these site differences, such as water availability and competition. The ag field site, although generally much drier than the pine cutover site, has virtually no competing woody vegetation, while the cutover site has substantially more woody competition.

Foliar N resorption efficiency was not significantly affected by fertilization, but tended to increase on the fertilized plots in both sites. These findings are in general agreement with Nelson and others (1995), who found no influence of fertilization on resorption efficiencies and Kuers and Steinbeck (1998), who observed an increase in resorption efficiency from 52.8 percent to 61.7 percent. The range of

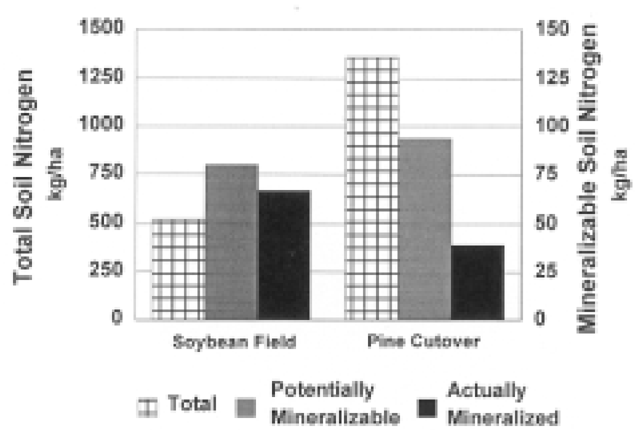

Figure 5—Total, potentially mineralizable, and actual soil N mineralized in two 4-year-old sweetgum stands of different land use history and soil type.

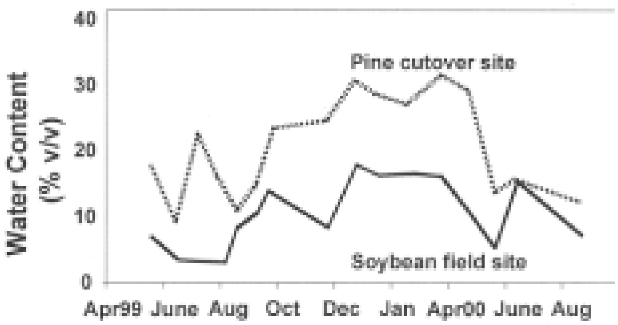

Figure 6—Volumetric soil water contents from April 1999 to September 2000 at two 4-year-old sweetgum stands of different land use history and soil type.

resorption efficiencies observed (41 percent to 52 percent) is low for sweetgum plantations. Resorption efficiency was higher on the cutover site than on the ag field site, indicating that factors other than nutrition, such as moisture availability, combined to control N resorption efficiency. del Arco and others (1991) found that resorption efficiency was lower on more xeric sites, suggesting that the drier soil of the ag field site may have reduced resorption efficiency.

Increases in foliar N content or concentration due to fertilization do not necessarily signify a foliar biomass response. Vector analysis (Krauss, 1965; Haase and Rose, 1995) was performed in this study using relative foliar N content, concentration, and foliage biomass for both sites (figure 7). In all cases except the 56 kg/ha N treatment on the ag field site, vector analysis indicated that the control plots were indeed deficient, and fertilization resulted in increases in foliar N content, concentration, and biomass. The length of the vectors gives an indication of the relative magnitude of the response to various treatments, and it is apparent from figure 6 that the response was much greater on the pine cutover site compared to the ag field site. The lower rate of fertilization on the ag cutover site was only enough to increase the foliar N content and concentration, but not cause an increase in foliar or tree biomass production relative to the control treatment.

Increasing foliar N concentrations can increase photosynthetic efficiency, but fertilizer applications in young stands are more useful as a means of increasing the total photosynthetic capacity through increased leaf area. In this study, the high rate of fertilization almost doubled the leaf area of the pine cutover stand, but fertilization had no significant effect on the ag field site. This indicates, like the vector analysis, that fertilization was much more effective on the pine cutover site compared to the ag field site.

Actual soil N supply, which would be predicted to be much higher at the pine cutover site due to its 6-fold greater soil organic matter (6 percent vs 1 percent), was almost half that of the ag field. Much more of the total organic N was in a recalcitrant form on the pine cutover site. Only 7 percent of the total soil N was potentially mineralizable on the cutover site, while 15 percent was potentially mineralizable on the ag field site. Furthermore, microbial immobilization and denitrification were likely much greater on the cutover site

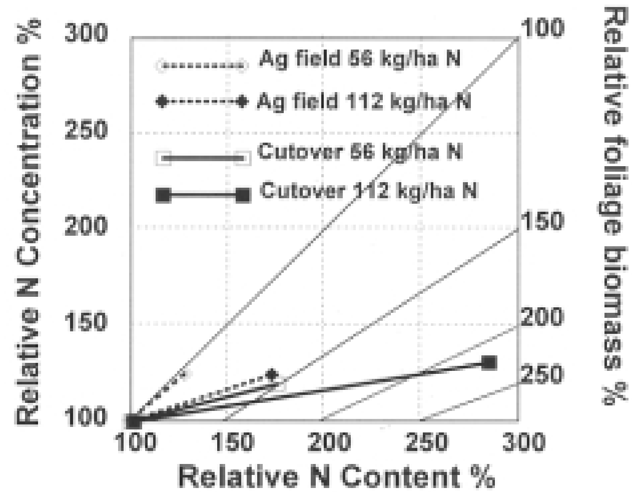

Figure 7—Vector analysis of relative responses in foliage biomass, N concentration, and N content in two 4-year-old sweetgum stands of varying land use history and soil type.

than at the ag site. The C:N ratio of the soil organic matter on the pine cutover site was 53, while only 28 at the ag site. Net immobilization is known to be greater as C:N ratios increase, and net N mineralization does not generally occur until the ratio is near 30. Preliminary findings from a related study indicate that fertilization may increase N mineralization on the pine cutover site. Denitrification may have been important on the cutover site due to wet but fluctuating moisture conditions (figure 6) and a high C energy source (Davidson and Swank 1987).

CONCLUSIONS

Developing efficient N management strategies for young sweetgum plantations and understanding plant responses to N fertilization requires an accurate estimate of actual soil N supply. This study showed that fertilizing young sweetgum plantations can result in large increases in foliar biomass, N content, and leaf area on some sites, but it may not be necessary on others. Simple estimates of soil N availability, such as organic matter content, total soil N, or even indices of potentially mineralizable N may not indicate the extent of plant response to N fertilizer; more accurate estimates of soil N availability that take environmental conditions into account as well are needed for developing N fertilizer recommendations for young hardwood plantations.

REFERENCES

Aerts, R.; F.S. Chapin III. 2000. The mineral nutrition of wild plants revisited: a re-evaluation of processes and patterns. Advances in Ecology Research 30: 1-67.

Blackmon, B. 1977. Cottonwood response to nitrogen related to plantation age and site. USDA Forest Service Southern Forest Experiment Statation Research Note SO-229: 3 p.

Bremner, J.M.; C.S. Mulvaney. 1982. Nitrogen - Total. p. 595-624. In: A.L. Page (ed.) Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd. Soil Science Society of America Publication No. 9. Part 2.

Burger, J.A.; W.L. Pritchett. 1984. Effects of clearfelling and site preparation on nitrogen mineralization in a southern pine stand. Soil Science Society American Journal 48: 1432-1437.

Davidson, E.; W. Swank. 1987. Factors limiting denitrification in soils from mature and disturbed southeastern hardwood forests. Forest Science 33: 135-144.

Eno, C.F. 1960. Nitrate production in the field by incubating the soil in polyethylene bags. Soil Science Society of America Proceedings 24: 277-279.

Guo, Y.; Lockhart, B.R.; T.T. Ku. 1998. Effect of nitrogen and phosphorus fertilization on growth in a sweetgum plantation in southeastern Arkansas. Southern Journal Applied Forestry 22: 163-168.

Haase, D.L.; R. Rose. 1995. Vector analysis and its use for interpreting plant nutrient shifts in response to silvicultural treatments. Forest Science 41: 54-66.

Krauss, H.H. 1965. Untersuchungenüber die Melioration degradierter Sandböden im nordostdeutschen Tiefland. Arch. Forstwes. 14:499-532.

Kuers, K.; K. Steinbeck. 1998a. Foliar nitrogen dynamics in Liquidambar styraciflua saplings: response to nitrogen fertilization. Canadian Journal Forest Research 28: 1671-1680.

Kuers, K.; K. Steinbeck. 1998b. Leaf area dynamics in Liquidambar styraciflua saplings: responses to nitrogen fertilization. Canadian Journal Forest Research 28: 1660-1670.

Nelson, L.E.; Shelton, M.G.; G.L. Switzer. 1995. The influence of nitrogen applications on the resorption of foliar nutrients in sweetgum. Canadian Journal Forest Research 25: 298-306.

SAS Institute. 1990. SAS/STAT User's Guide, Version 6 Edition. SAS Institute Inc., Cary, N. C.

Stanford, G.; S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Science Society America Proceeding 36: 465-472.

Torreano, S.J.; Frederick. 1988. Influence of site condition, fertilization and spacing on short rotation hardwood coppice and seedling yields. Biomass 16: 183-198.

Wittwer, R.F.; Immel, M.J.; F.R. Ellingsworth. 1980. Nutrient uptake in fertilized plantations of American sycamore. Soil Science Society America Journal. 44: 606-610.

THE EFFECTS OF HARVESTING ON LONG-TERM SOIL PRODUCTIVITY IN SOUTHERN INDIANA OAK-HICKORY FORESTS

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Abstract—Timber harvesting has the potential to alter long-term soil productivity in a variety of forest ecosystems. We monitored the effects of harvesting on N cycling processes in upland oak-hickory forests of southern Indiana, using a chronosequence of stands ranging in age from 1 year to 100 years after harvest. N cycling pools and processes were monitored from 1995-1999. Results suggest that reestablishment of fine root biomass occurs long before recovery of leaf area. The forest floor increases in relative importance for nutrient cycling with stand age. Litter decomposition is similar among stand ages. Estimates of actual evapotranspiration were significantly correlated with N cycling at most stages of forest development. There is a balance of litter N inputs, N mineralization, and N uptake at all stages of stand regeneration except at maturity. At this stage, litter N inputs were generally lower than N mineralization and N uptake.

INTRODUCTION

Data from various studies on forest N cycling at different stages of stand development can be used to reach general conclusions about ecosystem integrity, stand regeneration and nutrition, and recovery of N cycling pools and processes. Organization of the data into a conceptual model of N balances is one approach that can be used to make these assessments.

Two of the keys to the development of N cycling models are 1) the identification of the major ecosystem N pools and the transfer rates among these pools, and 2) an understanding of the degree to which N cycling is governed by internal pools and processes and external environmental factors.

For temperate hardwood forests, soil inorganic N is the major pool from which N is taken up for plant growth and metabolism (Nadelhoffer and others 1984). Much of the N is derived from the decomposition of vegetative N demand and uptake (Gholz and others 1985, Hendrickson 1988, Crow and others 1991). This may lead to a net loss of ecosystem N. As regeneration proceeds, this may lead to N limitations and reduced long-term site productivity. Only by monitoring N cycling at different stages of forest development, though, can these inferences by confirmed.

MATERIALS AND METHODS

We monitored various aspects of N cycling across a 100-year chronosequence of upland oak-hickory forests in southern Indiana, USA. Vegetation and site characteristics are listed in table 1. All of the regenerating stands were clear-cut harvested and represent different stages of forest development from recently-harvested through maturity. Litter production, litter decomposition, N mineralization and nitrification, N uptake, and soil temperature, moisture, and actual evapotranspiration were monitored from 1995-1999, although not all measurements were made in all years.

The data were compiled into a conceptual model of nutrient cycling, and simple correlation analysis was used to discover the relative strength of internal and external controls over N cycling at different stages of forest development. The basic design of the N balance model is similar to the one presented by Aber and others (1991) for the nutrient cycling model VEGIE (figure 1).

In the conceptual models below, boxes represent ecosystem pools of N. Arrows between boxes represent transfer rates of N. Circles represent factors that influence N cycling pools and processes. Pool sizes and transfer rates are given in kg N ha/yr per yr. Values inside circles represent the strength of the correlation (R-value). Because annual rates of N cycling were of interest, the year 1998, in which data was collected from April-December, was used to make assessments of net N mineralization, net nitrification, N uptake, and soil microbial biomass N (SMBN). During 1997 and 1999, N cycling measurements were made during fewer months of the year, so these data were not considered to be representative of annual N cycling rates. Relationships between AET and SMBN, AET and net N mineralization, and between net N mineralization, nitrification, and N uptake, however, were all based on three-year cumulative data. Data for fine root mortality and litter pool size come from Idol and others (2000). Data for litterfall

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and forest floor mass come from Idol and others (1998). Data for woody debris come from Idol and others (1999). A question mark (?) represents missing data in the model.

RESULTS AND DISCUSSION

80-100 Year-Old Stand

Figure 2 illustrates the N balance model for the mature, 80-100 year-old stand. This forest should be near steady-state N cycling as discussed by Attiwill and Adams (1993). Specifically, there should be a balance of litter decomposition, net N mineralization, and subsequent litter N return. According to the N balance model, annual net N mineralization (150 kg N/ha) and N uptake (142 kg N/ha) are quite similar, but N returns from annual fine root mortality plus aboveground litterfall are somewhat lower (102 kg N/ha). N returns from woody debris are unknown but are likely to be small relative to fine root and litterfall returns, as this stand has not yet reached an old-growth stage where there is significant mortality of overstory stems (Jenkins and Parker 1998, Spetich and others 1999). Annual litterfall may have been underestimated by 10-20 percent because only autumnal litterfall was collected (Idol and others 1998). Even so, total litter returns are still 30-35 kg N/ha less than total N uptake. Assuming a woody production rate of approximately 5 Mg/ha with a N concentration of 0.2-0.4 percent (Perry 1994), perennial biomass N accumulation probably does not exceed 10-20 kg N/ha. Fruiting structures such as acorns (oaks), nuts (beech and hickories), and samaras (maples) may account for some of the remaining N.

1-8 Year-Old Stands

Figure 3 illustrates the N balance model for forest stands aged 1-8 years after harvest. Although woody debris (WD) from logging slash adds a significant quantity of organic matter to the litter pool (Idol and others 1999), the total N content is comparable to that found in the mature forest stand (156 kg N/ha). Because higher soil temperatures in the regenerating stands may lead to faster decomposition rates, the decay of this poor quality WD litter likely leads to an increase in soil microbial biomass N (SMBN) (283 kg N/ha). This increase in SMBN may depress annual net N mineralization rates in the first year or two after harvest (110 kg N/ha). By 6-8 years after harvest, however, SMBN is similar to pre-harvest levels (150 kg N/ha). At 6-8 years, net N mineralization and N uptake from the A (80 kg N/ha) but not the B (~50 kg N/ha) horizon is also similar to preharvest levels. Fine root mortality (55 kg N/ha) and the fine root litter pool (18 kg N/ha) are similar to preharvest levels.

Net N mineralization, N uptake, and litter production balance quite well in the model of recently harvested stands (figure 3). Although no data on fine root mortality or litterfall were collected for the stand aged 1-3 years, estimates at 4-5 years suggest these litter sources probably add 110-130 kg N/ha annually. Annual net N mineralization and N uptake also range from 110-130 kg N/ha. This suggests that little incremental biomass is being accumulated during the early stages of forest regrowth. This agrees with earlier studies that showed recently-harvested stands in this region are dominated by herbaceous annuals and perennials (Matson and Vitousek 1981, Idol and others 2000), plants that retain little residual biomass from year to year.

Table 1—Vegetation and Soil Characteristics for a Chronosequence of Upland Oak-Hickory Forests in Southern Indiana

Stand Age	Major Canopy Species	Major Understory Species	Dominant Soil Series	Soil Horiz.	Bulk Density ($g\ cm^{-3}$)	pH	Total C	Total N
						——($g\ cm^{-3}$)——		
0-8	*Liriodendron tuplipifera* *Quercus alba*	*Smilax* spp. *Rubus* spp	Gilpin	A	1.20	5.41	35.1	4.63
				B	1.32	4.88	6.10	1.26
10-15	*Prunus serotina* *Quercus Rubra*	*Asimina triloba* *Sassafras albidum*	Gilpin	A	1.05	5.50	31.2	4.43
				B	1.35	4.81	5.84	1.01
30-35	*Acer saccharum* *Prunus Serotina*	*Acer saccharum* *Asimina triloba*	Gilpin/ Wellston	A	0.95	4.59	31.3	4.68
				B	1.10	4.71	5.42	1.14
80-100	*Quercus alba*	*Acer saccharum*	Wellston	A	1.02	4.59	27.4	4.12
				B	1.20	4.49	6.75	1.41

Sampled depths are 0-8 cm for the A and 8-30 cm for the B horizons.

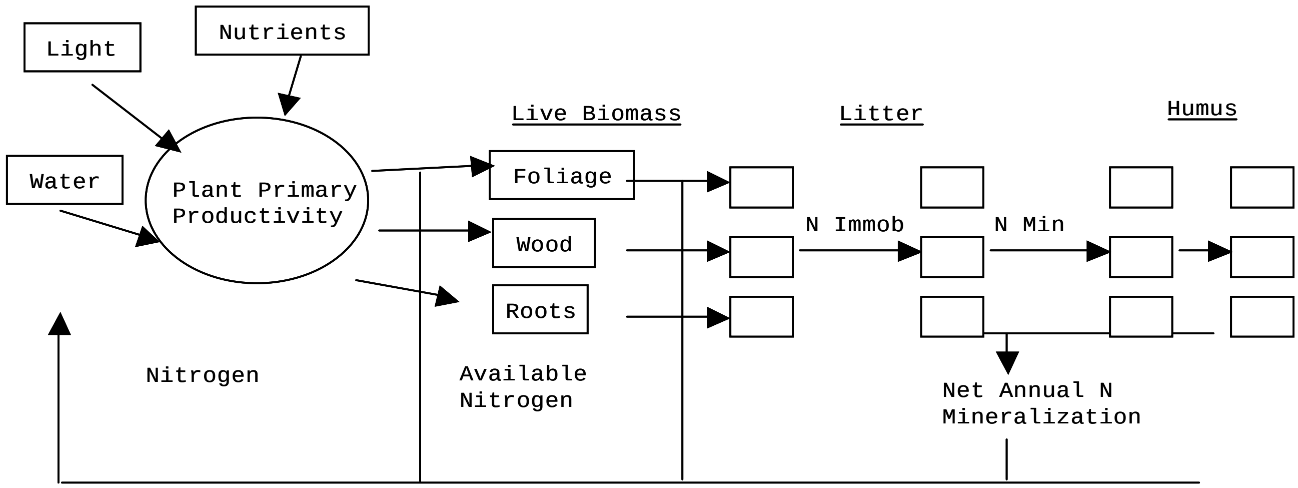

Figure 1—"VEGIE," a Generalized N Cycling Model (from Aber and others 1991). Values for boxes and arrows in kg N/ha-yr-1. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

10-15 Year-Old Stand

Figure 4 illustrates N cycling patterns at stand age 10-15 years. Annual litterfall N returns are lower than at 1-8 years (27 kg N/ha), but fine root turnover is higher (69 kg N/ha). Forest floor mass and the fine root litter pool are higher (69 and 26 N/ha, respectively), but the lack of large WD inputs plus a possible slowing of litter decomposition may contribute to lower SMBN in the A horizon (57 kg N/ha). The available N pool is somewhat lower in the A horizon (6.8 kg N/ha) but slightly higher in the B horizon (12 kg N/ha).

Net N mineralization in the A and B horizons (41 and 65 kg N/ha, respectively) is very similar to N uptake (44 and 67 kg N/ha, respectively). The total N uptake rate (111 kg N/ha) is slightly higher than the total litter production rate (96 kg N/ha), however, indicating some perennial biomass N accumulation. This is to be expected at this stage of forest development, as there is intense competition among tree saplings to reach the canopy before full canopy closure. Assuming a woody tissue N concentration of 0.2-0.4 percent, this balance of N uptake translates into a perennial biomass production rate of 12.5-25 Mg ha/yr.

30-35 Year-Old Stand

Figure 5 illustrates N cycling patterns at 30-35 years post-harvest. Annual litterfall N returns are higher at this stage

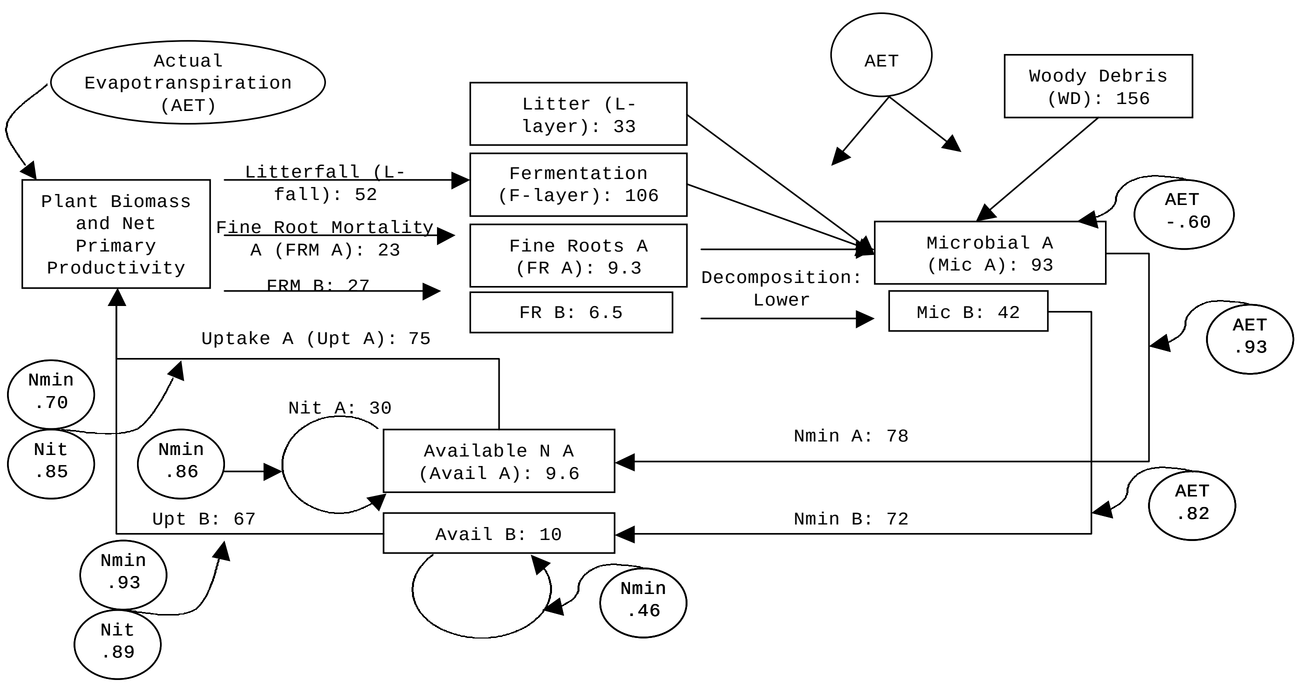

Figure 2—N Balance Model in an 80-100 Year Old Southern Indiana Upland Hardwood Forest. Values for boxes and arrows in kg N/ha/yr. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

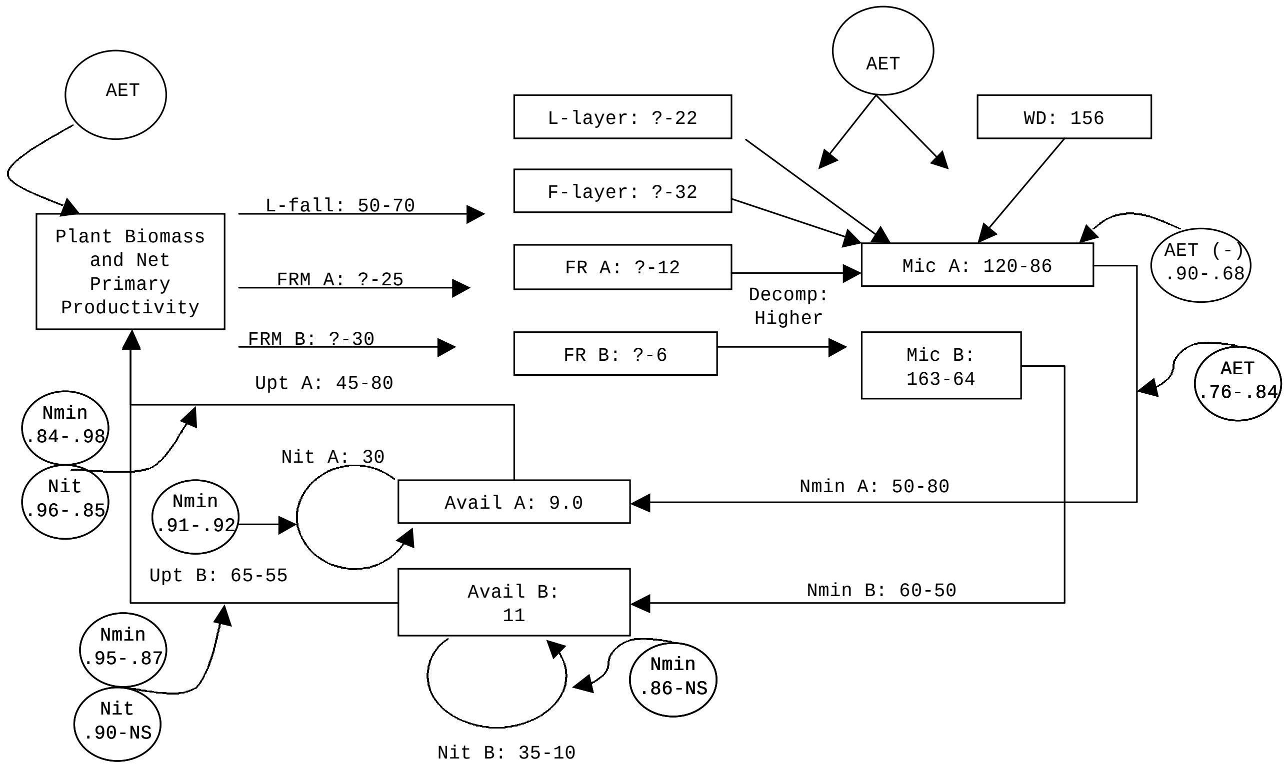

Figure 3—N Balance Model in Southern Indiana Upland Hardwood Forest Stands 1-8 Years Post-Harvest. Values for boxes and arrows in kg N/ha/yr. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

(38 kg N/ha) than at 10-15 years (27 kg N/ha), reflecting increased leaf area with increased stand age. Fine root mortality is similar in the A horizon (30 kg N/ha) but lower in the B horizon (32 kg N/ha). Forest floor mass is higher (98 kg N/ha), but the dead fine root pool is slightly lower (18 kg N/ha). Decomposition is assumed to be lower at this stage of forest development, but the SMBN pool is somewhat higher (141 kg N/ha) than at 10-15 years of age (112 kg N/ha), perhaps due to declining aboveground litter quality. The available N pool is somewhat higher in the A horizon (7.6 kg N/ha) but lower in the B horizon (9.0 kg N/ha).

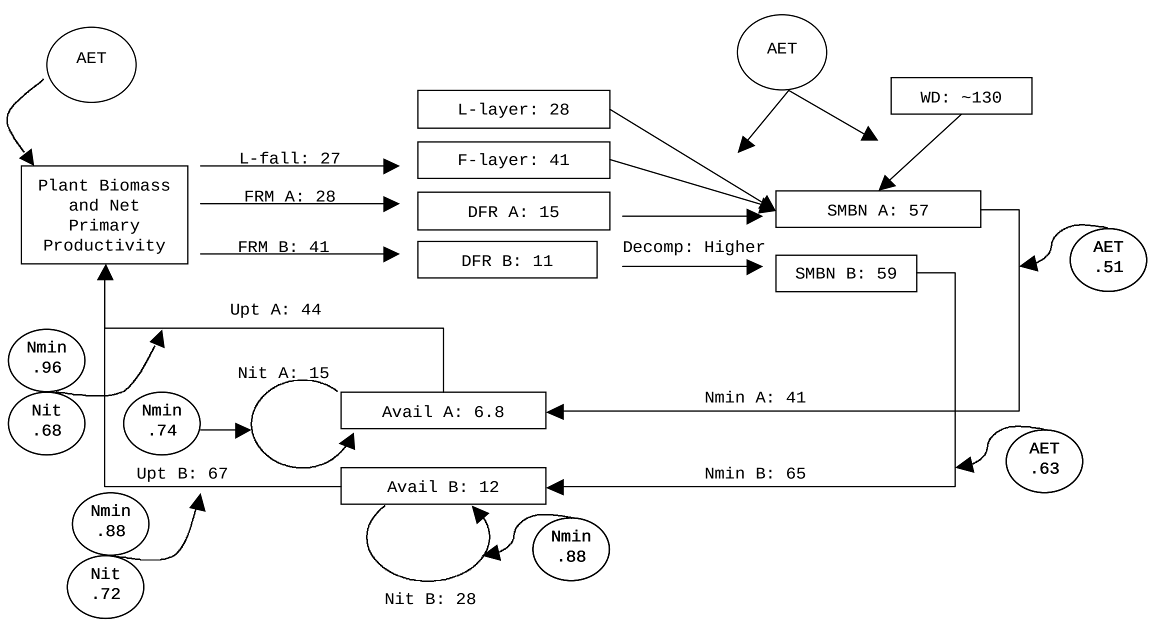

Figure 4—N Balance Model in a 10-14 Year-Old Southern Indiana Upland Hardwood Forest. Values for boxes and arrows in kg N/ha/yr. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

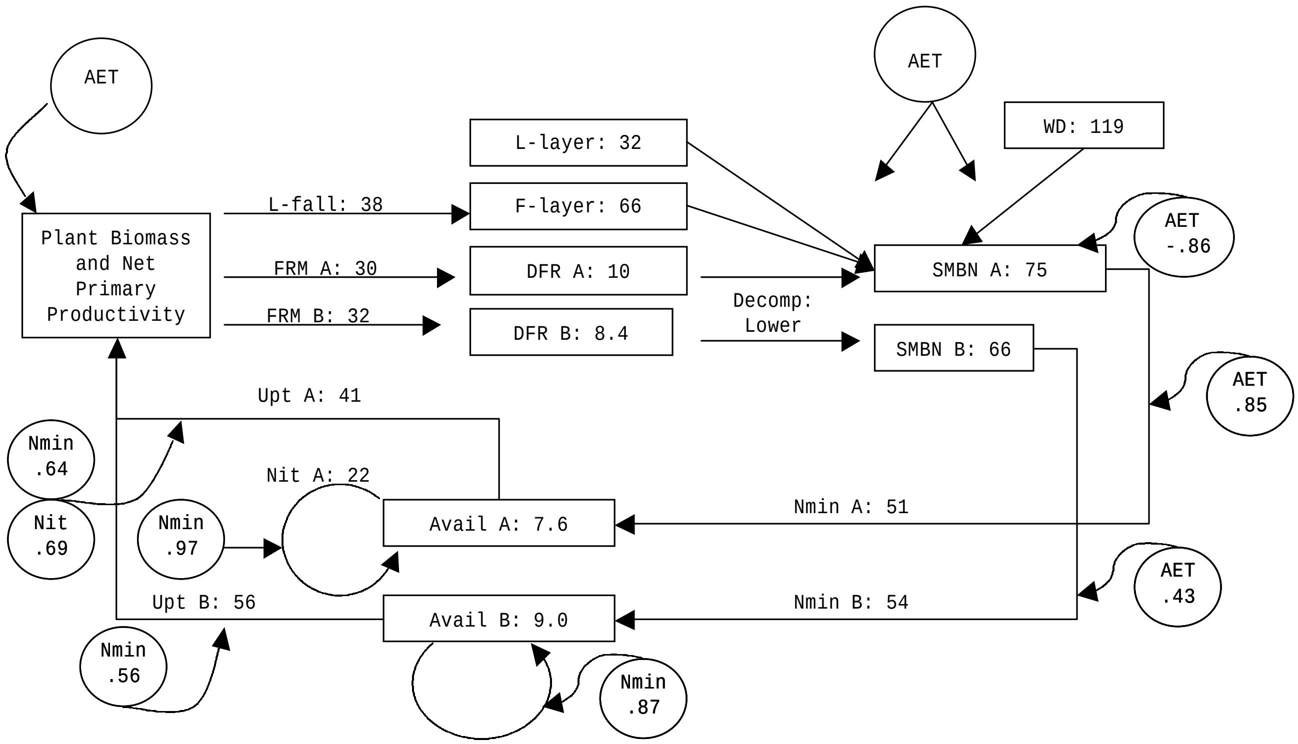

Figure 5—N Balance Model in a 29-33 Year-Old Southern Indiana Upland Hardwood Forest. Values for boxes and arrows in kg N/ha/yr. Values in circles represent strength of correlations (Pearson's correlation coefficient, R).

In the B horizon, net N mineralization (54 kg N/ha) is similar to N uptake (56 kg N/ha), but in the A horizon, net N mineralization (51 kg N/ha) is somewhat greater than N uptake (41 kg N/ha). Total N uptake (97 kg N/ha) and net N mineralization (105 kg N/ha), however, were similar to total litter production (100 kg N/ha), indicating that perennial plant growth may be slowing in this stand, and N cycling is approaching steady-state. This is in contrast to the higher net N mineralization and uptake (~145 kg N/ha) vs. total litter production (102 kg N/ha) rates in the mature forest stand (figure 2).

Controls Over N Cycling Rates

In stands of all ages, actual evapotranspiration (AET) correlates significantly and in some cases strongly with net N mineralization and N uptake. There is no consistent pattern with stand age, but in general relationships were stronger between AET and N cycling in the A horizon than in the B horizon. Relationships were generally strongest with net N mineralization and weakest with soil microbial biomass N and net nitrification.

The strongest relationships, however, were among the N cycling processes themselves. In general, net nitrification and N uptake were more strongly correlated with net N mineralization than with AET. In stands that are N-limited, N supply rates likely exert the strongest control over nitrification and N uptake, with environmental conditions (e.g., soil moisture and temperature) influencing the rate at which available N is nitrified or immobilized by plants or soil microorganisms.

CONCLUSIONS

The conceptual models presented in this study were derived from investigations of N cycling pools and processes at different stages of forest development. In general, there was a good balance of N mineralization, N uptake, and litter N returns in the regenerating forest stands; however, in the mature stand, there seemed to be more N taken up than returned via fine roots and autumnal litterfall. N mineralization and uptake were higher in the mature stand (140-150 kg ha/yr) than in the regenerating stands (80-100 kg ha/yr). Although actual evapotranspiration (AET) correlated significantly with N cycling processes at all stages of forest development, nitrification and N uptake correlated more strongly with N mineralization than with AET. Thus, although N cycling processes are well-balanced at different stages of forest development, harvesting may lead to declines in overall N cycling rates for at least the first 30-35 years.

REFERENCES

Aber, J.D.; Melillo, J.M.; Nadelhoffer, K.J.; Pastor, J.; Boone, R.D. 1991. Factors controlling nitrogen cycling and nitrogen saturation in northern temperate forest ecosystems. Ecological Applications. 1: 303-315.

Attiwill, P.M.; Adams, M.A. 1993. Tansley review No. 50. Nutrient cycling in forests. New Phytologist. 124: 561-582.

Crow, T.R.; Mroz, G.D.; Gale, M.R. 1991. Regrowth and nutrient accumulations following whole-tree harvesting of a maple-oak forest. Canadian Journal Forest Research. 21: 1305-1315.

Frazer, D.W.; McColl, J.G.; Powers, R.F. 1990. Soil nitrogen mineralization in a clearcutting chronosequence in a Northern California conifer forest. Soil Science Society America Journal. 54: 1145-1152.

Gholz, H.L.; Hawk, G.M.; Campbell, A.; Cromack, Jr. K.; Brown, A.T. 1985. Early vegetation recovery and element cycles on a clear-cut watershed in western Oregon. Canadian Journal Forest Research. 15: 400-409.

Hendrickson, Q.Q. 1988. Biomass and nutrients in regenerating woody vegetation following whole-tree and conventional harvest in a northern mixed forest. Canadian Journal Forest Research. 18: 1427-1436.

Idol, T.W.; Pope, P.E.; Figler, R.A.; Ponder, Jr., F. 1999. Characterization of coarse woody debris across a 100 year chronosequence of upland oak-hickory forests. In: Stringer, J.W.; Loftis, D.L., eds. Proceedings 12th central hardwood forest conference. Gen. Tech. Rep. SRS-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 60-67.

Idol, T.W.; Pope, P.E.; Ponder, Jr., F. 2000. Fine root dynamics across a chronosequence of upland oak-hickory forests. Forest Ecology Management. 127: 153-167.

I**dol, T.W.; Pope, P.E.; Tucker, J.; Ponder, Jr. F.** 1998. The role of fine root dynamics in the N and P cycles of regenerating upland oak-hickory forests. In: Waldrop, T.A., ed. Proceedings 9th Biennial Southern Silvicultural Research Conference. Gen. Rep. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 136-140.

Jenkins, M.A.; Parker, G.R. 1998. Composition and diversity of woody vegetation in silvicultural openings of southern Indiana forests. Forest Ecology Management. 10: 57-74.

Matson, P.A.; Vitousek, P.M. 1981. Nitrogen mineralization and nitrification potentials following clearcutting in the Hoosier National Forest, IN. Forest Science. 27: 781-79.

Nadelhoffer, K.J.; Aber, J.D.; Melillo, J.M. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. Plant Soil. 80: 321-335.

Perry, D.A. 1994. Forest ecosystems. Baltimore: John Hopkins University Press. 649 p.

Pritchett, W.L.; Fisher, R.F., eds. 1987. Properties and management of forest soils. New York: Wiley.

Spetich, M.A.; Parker, G.R. 1999. Regional distribution and dynamics of coarse woody debris in midwestern old-growth forests. Forest Science. 45: 302-313.

THE RELATIONSHIP BETWEEN SOILS AND FOLIAR NUTRITION FOR PLANTED ROYAL PAULOWNIA

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Abstract—Royal paulownia is becoming an important hardwood plantation species in the southern U.S. A study was done to investigate two novel site preparation techniques for aiding the establishment of royal paulownia seedlings in the Virginia Piedmont. The effects of these treatments on the foliar nutrition of first year seedlings was determined, as was the relationship between soil fertility levels and foliar nutrition in the three study blocks. Seedlings established following both trenching and subsoiling treatments had significantly higher levels of foliar P than the control seedlings. Seedlings growing in the trenched plots had higher levels of foliar N than the control seedlings. For example, the seedlings growing in the trenched plots had average foliar N levels of slightly over 25,000 mg/kg, while the control seedlings had levels of 17,250 mg/kg. The seedlings in control plots also had lower, but not significantly so, foliar levels of K, Ca, Fe, and Mn. Soil fertility levels, based on soil test measurements, had positive and significant relationships with the foliar nutrient levels, as determined by simple linear regression.

INTRODUCTION

Royal paulownia (*Paulownia tomentosa* (Thurb.) Steud.) is becoming an important hardwood plantation species in the Southern U.S. Originally introduced to the U.S. from China in the early 1800's, royal paulownia has become naturalized throughout much of the eastern U.S. Today the markets for paulownia wood remain in Japan, where the wood is used for a variety of products, including lumber for furniture, handicrafts, musical instruments, shoes, etc. (Hardie and others 1989). Landowners are interested in techniques for establishing and growing paulownia tree crops for the export market (Johnson and others 1992, Kays and others 1998).

This study was established to investigate the usefulness of two novel site preparation techniques, trenching and subsoiling for early establishment and growth of royal paulownia. Paulownia growth is best in China on light textured soils, with clay contents less than 10 percent (Zhao-Hua and others 1997). The heavy textured soils found in the Piedmont have proven problematic for paulownia establishment, survival, and growth. One aspect of paulownia field performance, foliar nutrition, will be reported here.

METHODS

Study Area

The study was established at Virginia Tech's Reynolds Homestead Forest Resources Research Center located in the Piedmont physiographic province in Patrick County, Virginia (latitude 36°40′N, longitude 80°10′W). Three abandoned agricultural fields were selected for the study sites, with each field representing a complete block. All three fields were in grass and broad-leaved weed cover.

The study area experiences a warm, humid continental climate, with a mean annual temperature of 15°C, mean annual precipitation of 114 cm, and mean growing season precipitation of 79 cm. Temperatures typically range from -1°C in winter to 29°C in summer. The normal growing season length is 190 days, with April 20 as the most likely date of the last killing frost in the spring, and November 1 as the most likely date of the first killing frost in the fall.

Soils in the study area are in the Cecil series, and are clayey, kaolinitic, thermic Typic Hapludults. These soils are deep and well-drained, and formed in weathered granite gneiss, quartz schist, and quartzite. The A horizons are thin to absent due to surface erosion when the fields were in agricultural production.

Seedling Propagation

Seed pods were collected from selected wild trees growing in southwestern Virginia and air-dried, and then seeds were extracted and stored in sealed containers at 4°C. In the late summer of 1993, seeds were broadcast sown in greenhouse flats containing a 1:1 by volume mixture of Pro-Mix BX® and sand. Following germination, the germinants were manually transplanted into cone-tainers, with two to four germinants per pot. The seedlings were grown in a heated (temperature above 15°C) greenhouse under

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Table 1—Soil chemical properties for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	pH	Anaerobically Mineralized N (mg/kg)	Total N (mg/kg)	Total C (%)	Extractable (mg/kg)					
						P	K	Ca	Mg	Fe	Mn
1	Subsoil	5.7	24.0	636	0.98	0.12	40.6	420.5	157.4	1.83	16.9
	Trench	5.4	23.7	705	1.06	0.12	32.8	415.9	77.2	1.00	50.2
	Control	5.5	32.8	776	1.16	0.12	61.9	430.2	145.0	1.49	35.6
	Mean	5.5	26.8	706	1.07	0.12	45.1	422.2	126.5	1.44	34.2
2	Subsoil	5.7	26.4	701	1.16	0.12	31.2	394.0	122.9	2.20	7.3
	Trench	5.5	20.6	619	0.95	0.12	25.0	374.9	130.9	5.89	4.8
	Control	5.4	18.6	617	0.96	0.12	20.3	421.5	143.1	4.24	4.7
	Mean	5.5	21.8	646	1.02	0.12	25.5	396.8	132.3	4.11	5.6
3	Subsoil	5.4	31.5	598	1.05	0.97	81.9	314.7	112.0	2.90	6.7
	Trench	5.7	39.1	651	1.01	2.31	99.8	410.5	143.8	2.58	7.9
	Control	5.6	51.1	708	1.05	4.18	89.8	359.3	116.0	3.48	8.9
	Mean	5.5	40.5	652	1.03	2.49	90.5	361.5	123.9	2.99	7.8

natural light conditions, with water and nutrients added regularly, for 14 weeks. After 3 weeks, the most vigorous seedling in each pot was selected and the others were removed. Following the 14-week greenhouse period, the pots were moved outside to a slathouse and allowed to harden off until planting.

Site Preparation and Plantation Establishment

During the early spring of 1994, three site preparation treatments were installed on 0.05-ha plots in the three blocks. Treatment one consisted of drawing a single subsoil shank behind a tractor on a 2-m x 2-m grid throughout the block. The subsoil shank penetrated to a depth of approximately 75 cm, creating a grid pattern. Treatment two consisted of creating a 2-m x 2-m grid of 10 cm-wide x 60 cm-deep trenches throughout the block. The trenches were filled with soil and two loblolly pine (*Pinus taeda*) poles placed at depths of 40 and 25 cm. The pine poles were cut from a thinning operation in a nearby plantation. The purpose of both the subsoil and trenching treatments was to break up the dense subsoil and create

Table 2—Soil physical properties for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	Bulk Density (g/cm^3)	Soil Strength (kg/cm^2)	Soil Moisture (%)	Coarse Fragments (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class
1	Subsoil	1.2	4.99	35.0	0.7	35	28	37	clay loam
	Trench	1.4	8.44	25.8	0.8	40	23	38	clay loam
	Control	1.2	5.48	32.0	0.6	38	28	34	clay loam
	Mean	1.3	6.33	30.9	0.7	38	26	36	clay loam
2	Subsoil	1.4	9.42	20.6	12.4	44	22	34	clay loam
	Trench	1.3	7.87	21.2	5.9	47	20	34	sandy clay loam
	Control	1.5	7.38	21.2	12.1	46	19	37	sandy clay loam
	Mean	1.4	8.23	21.0	10.1	46	20	35	clay loam
3	Subsoil	1.6	8.86	21.0	17.6	38	32	31	clay loam
	Trench	1.5	7.95	21.6	15.1	42	28	31	clay loam
	Control	1.6	9.35	22.2	25.5	46	26	29	clay loam
	Mean	1.6	8.72	21.6	19.4	42	29	30	clay loam

Table 3—Foliar nutrient levels for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	N	P	K	Ca	Mg	Fe	Mn
		Foliar Nutrient Level (mg/kg)						
1	Subsoil	14,800	1,420	7,790	10,940	3,090	218	24
	Trench	24,500	1,700	9,820	8,550	2,870	82	53
	Control	17,000	1,400	9,020	7,910	2,890	103	22
	Mean	18,800	1,510	8,880	9,130	2,950	134	33
2	Subsoil	21,900	1,360	8,670	7,600	3,380	59	21
	Trench	22,700	1,450	7,710	7,540	3,680	80	20
	Control	12,900	1,010	5,140	6,350	2,630	229	16
	Mean	19,200	1,270	7,170	7,160	3,230	123	19
3	Subsoil	29,600	3,540	14,240	5,070	3,680	65	20
	Trench	28,000	3,290	12,890	6,480	3,950	64	20
	Control	21,900	2,590	10,980	7,140	4,050	72	19
	Mean	26,500	3,140	12,700	6,230	3,890	67	20

root channels for the planted seedlings. The final site preparation treatment consisted of a control.

During May of 1994, 100 containerized royal paulownia seedlings were hand-planted on a 2-m x 2-m grid in each of the site-prepared plots, at the intersections of the subsoil channels or the trenches. In the control plots, the planting spots were hand-scalped, but this was not necessary in the site-prepared plots since there was adequate surface disturbance to remove the sod cover. As a secondary treatment, each plot was split into two subplots, and 50 seedlings in each subplot were surrounded with a 91-cm x 91-cm Vispore® weed mat. An additional 50 seedlings were left untreated.

Soil Sampling and Field Measurements

Prior to the installation of site preparation treatments, soil characterization samples were collected from each of the 18 subplots in the study. Five 30 cm-deep push tube samples were collected from random locations in each subplot, then composited in the field.

Simultaneously with the collection of samples for soil characterization, soil moisture samples were collected at the same five locations, to a depth of 15 cm. These samples were likewise composited and returned to the lab for gravimetric analysis. Comparative soil strength measurements were also obtained at the same locations, using a SOILTEST penetrometer to a depth of 5 cm. Additionally, three randomly located bulk density samples, to a depth of 5 cm, were collected in each subplot using an AMS soil core sampler.

Following installation of the site preparation treatments, gravimetric soil moisture samples were collected again from five random locations within each subplot. Soil penetrometer measurements were also repeated. In the control plots, five readings were made in random locations

Table 4—Site preparation treatment effects on royal paulownia foliar nutrient levels

Site Preparation Treatment	N	P	K	Ca	Mg	Fe	Mn
	Foliar Nutrients (mg/kg)						
Subsoil	22,100 ab[1]	2,110 a	10,240 a	7,870 a	3,380 a	114 a	21 a
Trench	25,100 a	2,150 a	10,140 a	7,520 a	3,500 a	75 a	31 a
Control	17,300 b	1,670 b	8,380 a	7,140 a	3,190 a	135 a	19 a

[1]Means followed by the same letter are not significantly different at the 0.10 level.

within each subplot. In the site-prepared plots, five readings per subplot were randomly taken in the subsoil channels and trenches, as well as in the undisturbed portions of the subplots. Likewise, the bulk density sampling was repeated in a fashion similar to the penetrometer measurements, except three bulk density samples were collected from each of the disturbed and undisturbed areas of the site-prepared subplots.

Foliar Sampling

During September 1994, sun leaves from four randomly selected seedlings in each site preparation treatment within each block were harvested and allowed to air-dry in paper bags.

Laboratory Methods

The characterization soil samples were air-dried and ground to pass a 2-mm sieve. Available P, K, Ca, Mg, Fe, and Mn were extracted using the dilute double-acid procedure with 0.05N HCl and 0.025N H_2SO_4 (Kuo 1996), with the extract analyzed using a Jarrell-Ash ICAP-9000 inductively coupled plasma emission spectrometer. An estimate of nitrogen availability was determined using the anaerobic incubation technique (Keeney 1982). Total nitrogen was determined using the micro-Kjeldahl method (Bremner and Mulvaney 1982). Soil pH was determined using a glass electrode in a 2:1 soil:water mixture. Percent organic carbon was determined using a LECO CR-12 carbon analyzer, and particle size analysis was conducted using the hydrometer method. Bulk density was determined gravimetrically, with correction for coarse fragments greater than 2 mm.

Foliage was oven-dried to a constant weight at 65°C, then ground in a Wiley mill to pass a 1-mm sieve. The ground tissue was dry-ashed in a muffle furnace at 500°C, dissolved in 6N HCl and analyzed for P, K, Ca, Mg, Fe, and Mn using a Jarrell-Ash ICAP-9000 inductively coupled plasma emission spectrometer. Total nitrogen was determined using the micro-Kjeldahl method (Bremner and Mulvaney 1982).

Statistical Analysis

This study was established as a randomized complete block, split-plot design, with site preparation treatments as major plots and a weed control mat treatment comprising the minor plots. There were three major plot site preparation treatments (subsoil, trench, and control) randomly applied in each of the three blocks, and two weed control treatments (mat or no-mat) applied to two subplots within each major plot. Thus, there were three blocks, three plots per block, and two subplots per plot. Each subplot had 50 seedlings. All measurements were averaged at the subplot level to create the experimental unit.

Foliar nutrient levels were subjected to an analysis of variance, followed by Duncan's Multiple Range Test at the 0.10 level. The analysis of variance revealed no effect of the weed control mats, so this factor was dropped from further analysis. Soil and foliar nutrient levels were compared using simple linear regression analysis.

RESULTS AND DISCUSSION

Soil Properties

Soil chemical and physical properties are displayed in tables 1 and 2. All three blocks had similar pH levels, with 5.5 being the average for each block. Block 1 tended to have slightly higher levels of total soil N, although Block 3 had the highest level of anaerobically mineralized N, at 40.5 mg/kg. Total C levels ranged from 1.02 to 1.07 percent. Levels of soil P were quite low on Blocks 1 and 2, averaging only 0.12 mg/kg. Soil P in Block 3 averaged 2.49 mg/kg. Block 3 tended to be richer also in soil K. Bulk densities tended to be consistent across the blocks, ranging from 1.3 g/cm^3 in Block 1 to 1.6 g/cm^3 in Block 3 (table 2). On the date that soil moisture was sampled, Block 1 had comparatively higher levels, at 30.9 percent compared to 21.0 and 21.6 percent for Blocks 2 and 3, respectively. Block 1 also had much lower levels of coarse fragments, with only 0.7 percent by weight. Blocks 2 and 3 averaged 10.1 and 19.4 percent, respectively. Across the study area the predominant soil textural class was clay loam (table 2).

Foliar Nutrient Levels

Foliar nutrient levels for the sampled seedlings are presented in table 3. Some block to block differences were noted, as well as differences between the treatments (table 4). Foliar N levels ranged from 18,800 to 26,500 mg/kg (table 3). P levels ranged from 1,270 to 3,140 mg/kg. N, P, and K foliar levels were considerably higher in Block 3, which relates well to the soil fertility levels shown in table 1.

Treatment effects on foliar nutrient levels were noted with only two nutrients, N and P (table 4). For N the seedlings growing on the trenched plots had significantly higher levels than the control seedlings. The seedlings growing on the subsoiled plots had intermediate levels, but they were not significantly greater than the control seedlings. Foliar N levels ranged from a low of 17,300 mg/kg for the control seedlings to 25,100 mg/kg for the seedlings growing on the trenched plots. For foliar P, both site preparation treatments led to seedlings with significantly higher levels than the control seedlings (table 4). The range in foliar P was from 1,670 mg/kg for the control seedlings to 2,150 mg/kg for the seedlings growing in the trenched plots. No significant differences were noted for any of the other treatments.

Relationship Between Soil Fertility and Foliar Nutrient Levels

The relationship between soil fertility and royal paulownia foliar nutrition is shown graphically in figure 1. Soil nutrient levels were regressed against the foliar nutrient levels for N, P, K, and Ca. Data were pooled at the block level, since soil sampling did not match the root zone of the individual seedlings from which leaf samples were collected. Therefore, the data set is limited to the averages of the soil samples and leaf samples for the three blocks. Nevertheless, strong and positive correlations were determined for all of the nutrients studied. Coefficients of determination ranged from a low of 0.911 for N to a high of 1.00 for K (figure 1). The inference is that royal paulownia is quite

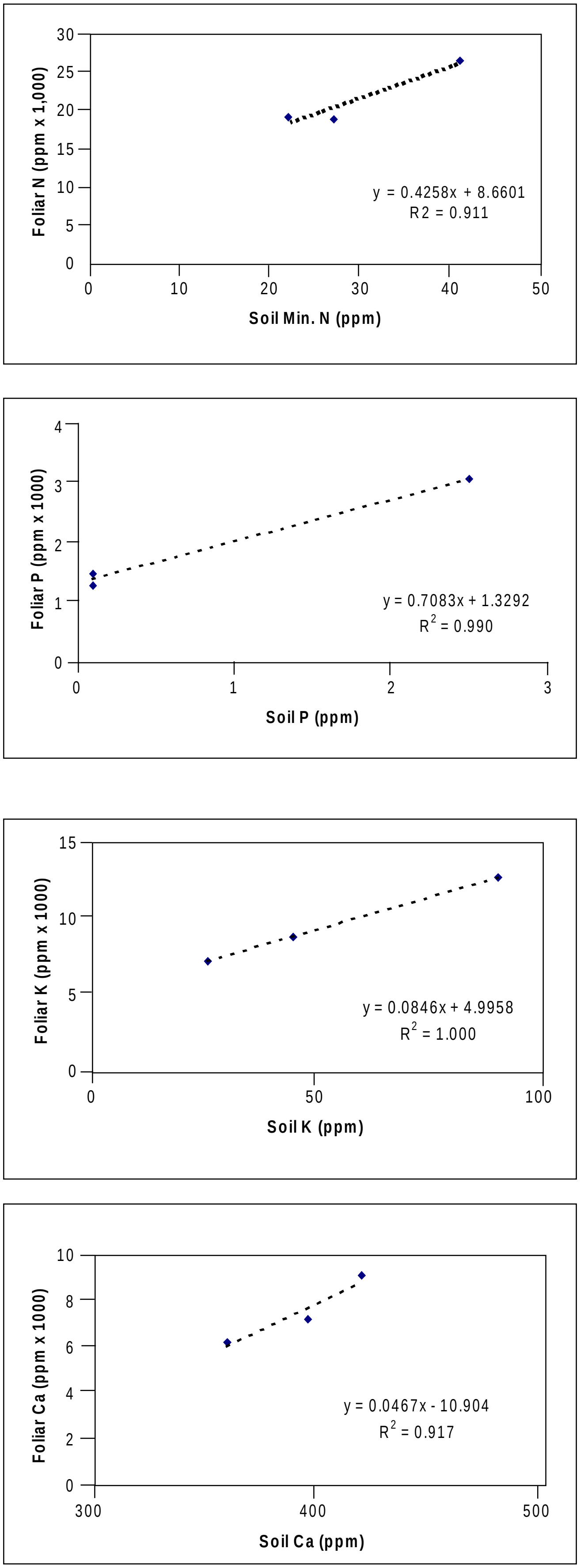

Figure 1—Relationships between soil fertility and royal paulownia foliar nutrition levels.

sensitive to soil fertility, a point that has been noted by others (Beckjord and McIntosh 1983, Graves and Stringer 1989). Although information on fertilizer regimes for royal paulownia are not well developed, it is apparent that foliar nutrition is closely related to soil nutrient levels, and fertilizer additions may be used to correct deficiencies. None of the seedlings in this study exhibited characteristic foliar nutrient deficiencies. Although leaf weights were not determined, royal paulownia seedlings and saplings are noted for having very large leaves. This indicates that on a total weight basis, paulownia may be quite demanding of nutrients. Foliar nutrition is also closely related to plant growth, so it is important to correctly balance foliar nutrient concentration (reported here) and nutrient content (Haase and Rose 1995, Cornelissen and others 1997).

CONCLUSIONS

Foliar nutrient levels for first year royal paulownia seedlings growing in plots of three different site preparation treatments were reported here. The treatments increased foliar concentrations of N and P, but did not affect foliar K, Ca, Mg, Fe, or Mn. Strong, positive correlations were found between soil fertility (expressed as extractable soil nutrients, or, in the case of nitrogen, anaerobically mineralizable) and foliar nutrient levels for N, P, K, and Ca. Royal paulownia appears to be quite sensitive to soil fertility, indicating that fertilization may be a viable treatment in areas of low fertility.

REFERENCES

Beckjord, P. J.; M. S. McIntosh. 1983. Paulownia tomentosa: effects of fertilization and coppicing in plantation establishment. Southern Journal of Applied Forestry. 7(2): 81-84.

Bremner, J. M.; Mulvaney, C. S. 1982. Nitrogen - total. In: Page, A. L.; Miller, R. H.; Keeney, D. R.,eds. Methods of Soil Analysis, Part 2. 2nd ed. Agronomy Series No. 9, Amer. Soc. of Agronomy, Madison, WI: 595-622.

Cornelissen, J. H. C.; M. J. A. Werger; P. Castro-Diez; J.W.A. van Rheenen; A. P. Rowland. 1997. Foliar nutrients in relation to growth, allocation and leaf traits in seedlings of a wide range of woody plant species and types. Oecologia 111: 460-469.

Graves, D. H.; Stringer, J. W. 1989. Paulownia — a guide to establishment and cultivation. Univ. of Kentucky Coop. Extension Serv. FOR-39. Lexington, KY. 8 p.

Haase, D. L.; R. Rose. 1995. Vector analysis and its use for interpreting plant nutrient shifts in response to silvicultural treatments. Forest Science. 41(1) 54-66.

Hardie, I.; Kundt, J.; Miyasaka, E. 1989. Economic feasibility of U.S. paulownia plantations. Journal of Forestry. 87(10): 19-24.

Johnson, J. E.; Pease, J. W.; Johnson, L. A.; Hopper, G. M. 1992. Tree crops for marginal farmland — royal paulownia, with a financial analysis. Virginia Cooperative Extension Pub. 446-606. Virginia Polytechnic Institute and State University, Blacksburg, VA. 22 p.

Kays, J.; Johnson, D.; Stringer, J. W. 1998. How to produce and market paulownia. Univ. of Maryland Cooperative Extension Service Bull. 319. College Park, MD. 22 p.

Keeney, D. R. 1982. Nitrogen—availability indices. In: Page, A. L.; Miller R. H.; Keeney, D. R., eds. Methods of Soil Analysis, Part 2. 2nd ed. Agronomy Series No. 9. America Society of Agronomy, Madison, WI: 722-730.

Kuo, S. 1996. Phosphorus. In: Sparks, D. L.;, ed. Methods of Soil Analysis, Part 3. Soil Science Society of America No. 5. Madison, WI: 869-919.

Zhao-Hua, Z.; Ching-Ju, C.; Xin-Yu, L.; Yao Gao, X. 1997. *Paulownia* in China: Cultivation and utilization. Asian Network for Biology Science and International Development Research Center, Ottawa, Canada. <http://www.idrc.ca/library/document/071235>.

GENOTYPE X FERTILITY INTERACTIONS IN SEEDLING SWEETGUM

Scott X. Chang and Daniel J. Robison[1]

Abstract—Genotype x fertility interactions may affect the suitability of sweetgum (*Liquidambar styraciflua* L.) for specific sites or the efficiency of nutrient use. To gain a better understanding of these interactions, 2-year-old sweetgum seedlings from two half-sib families were tested for growth response to N (0 and 100 kg/ha equivalent) and P (0 and 50 kg/ha equivalent) for one season in an outdoor pot study. Sweetgum seedlings responded rapidly to N and P treatments, in both stem and crown size. Nitrogen, P and family genotype explained 37, 21 and 10 percent of the response in basal diameter growth, respectively. The data suggest that screening sweetgum families for nutrient use efficiency may be worthwhile, and that balanced N and P applications are important for promoting seedling growth.

INTRODUCTION

Sweetgum (*Liquidambar styraciflua* L.) is an important hardwood timber species in the U.S. south (Kormanik 1990), and many hardwood plantations established for short-rotation pulpwood production in this region are sweetgum (Robison and others 1998). Developing genetically improved hardwoods for fast growth and high quality, and formulating site-specific and fertilization guidelines for hardwood plantation establishment have been rated as priorities for hardwood research in North America (Meyer 1996). A better understanding of the genetic variation in sweetgum growth response to silvicultural practices, such as fertilization, can improve the efficiency of timber production by best utilizing genetically improved planting stock.

Sweetgum families have been shown to respond differentially to N, but not to P applications (Nelson and Switzer 1990). Nelson and Switzer (1990) found significant family x fertility interactions for nitrogen. In three of the 4 families they tested, maximum growth response was at 200 kg N/ha, while the other half-sib family had its maximum growth response at 400 kg N/ha. Other studies in Mississippi by the same research group have reported various sweetgum genetic effects related to nutrition (Nelson and others 1995a, Nelson and Switzer 1992, Nelson and Switzer 1990, Nelson and others 1995b).

The current study examines genotype x fertility interactions in seedling sweetgum, using two half-sib families selected from among the circa 350 families in the NC State University - Hardwood Research Cooperative (NC State-HRC) genetic improvement program. These two families had in earlier work demonstrated substantially different responses to high and low fertility levels (Birks and Robison 2000). The aim of this work was to develop an understanding of the proportion of growth response attributable to genotype x fertility interactions. If such interactions are significant, then protocols for use in genetic selection, and site and fertilization decision-making, can be devised to best utilize specific genotypes. In the current study we specifically examine N and P fertility effects.

MATERIALS AND METHODS

This experiment was conducted in pots (22 cm diameter by 25 cm deep) out-of-doors at the Horticulture Field Laboratory of North Carolina State University in Raleigh, NC. Seed from two half-sib sweetgum families in the NC State-HRC program (F10022 and F10023), collected from a seed production area in St. George, SC (SC Forestry Commission land) were used in this work. Stratified seed were sown, two per pot from the same family, on 22 July 1999, into pots containing peat:vermiculite:field soil in a 6:3:1 (volume) ratio. The field soil (Congoree silt loam) was collected from an area with naturally occurring sweetgum in Raleigh, NC. After germination, all pots received a one-time application of 1.45 g of Osmocote™ slow-release fertilizer (14-14-14) to ensure adequate nutrition for healthy seedling development in the first growing season. Seedlings were thinned to one per pot in September 1999, to leave similarly sized plants among pots. Seedlings were overwintered outdoors and experimental treatments applied in the second growing season. Pots were widely spaced throughout the experiment to eliminate shading.

On 6 July 2000, four treatments were applied to both families, 1) no N or P (control), 2) no N and 50 kg/ha equivalent P, 3) 100 kg/ha equivalent N and no P, and 4) 100 kg/ha equivalent N and 50 kg/ha equivalent P. There were three pots for each family within each treatment. Fertilizers were applied as granular NH_4NO_3 and triple superphosphate. Pots received daily overhead irrigation.

Initial seedling size (ground-line basal diameter, total height, unit leaf weight, unit leaf area, and specific leaf area

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[SLA]) was measured on 23 June 2000. Leaf weight and area (then used to calculate SLA) were estimated by sampling five mid-crown fully expanded leaves from every tree. Final seedling size (same parameters as above, plus crown dimensions [height and width]) was measured on 7 September. Leaf samples were dried at 65 °C and weighed. Crown volume was calculated as a conoid from height and width measurements.

Statistical analyses were performed with SAS (SAS Institute, Cary, NC, Version 7.01).

RESULTS AND DISCUSSION

All initial seedling size measurements were compared by ANOVA among treatments. None differed significantly at $P < 0.05$ among treatment or family effects, or with any interactions. A few of the initial size measurements differed among treatments and families at $P < 0.10$. These were leaf weight among N, P and family factors, SLA by P levels, and height by family.

At the time of final measurements (two months after the treatments were applied) SLA was significantly ($P < 0.01$) affected by N, P, and an N x P interaction, but not by family (figure 1a). Without N addition seedling sweetgum SLA did not respond to P.

This response of SLA to N was consistent with those reported by Nelson and others (1995b). They reported SLA effects only three years after N application. In the current study we measured SLA changes in two months, and found a significant P effect. These changes in SLA suggest that when N and P are applied in correct proportion, seedlings will have greater photosynthetically active areas, and may grow more rapidly (Walters and Reich 1996). This may be of immediate relevance in sweetgum nurseries, and of longer-term importance in crown closure (and its effect on weeds) and productivity in field plantings. In herbaceous species it has been reported that nutrient additions do not impact SLA when photosynthetically active radiation is not limiting (Meziane and Shipley 1999), however our data indicates that sweetgum SLA was responsive to added nutrients under full light.

Initial and final basal diameters were significantly correlated, however initial and final heights were not. Basal diameter was affected by the experimental factors; family ($P < 0.01$), N ($P < 0.1$), and P ($P < 0.05$) (figure 1b). Family F10023 consistently had greater basal diameter than F10022, nitrogen addition was marginally significant at each P level, and P addition was significant regardless of the rate of N application. There were no interactions among these three factors with respect to diameter.

Seedling height was significantly affected by family ($P < 0.05$) and N application ($P < 0.05$) (figure 1c). However, in contrast to the findings for basal diameter growth, family F10022 was consistently taller than family F10023. No interactions with respect to height were found. In the current study the two month (current) growth increment was significant, corroborating earlier findings of rapid

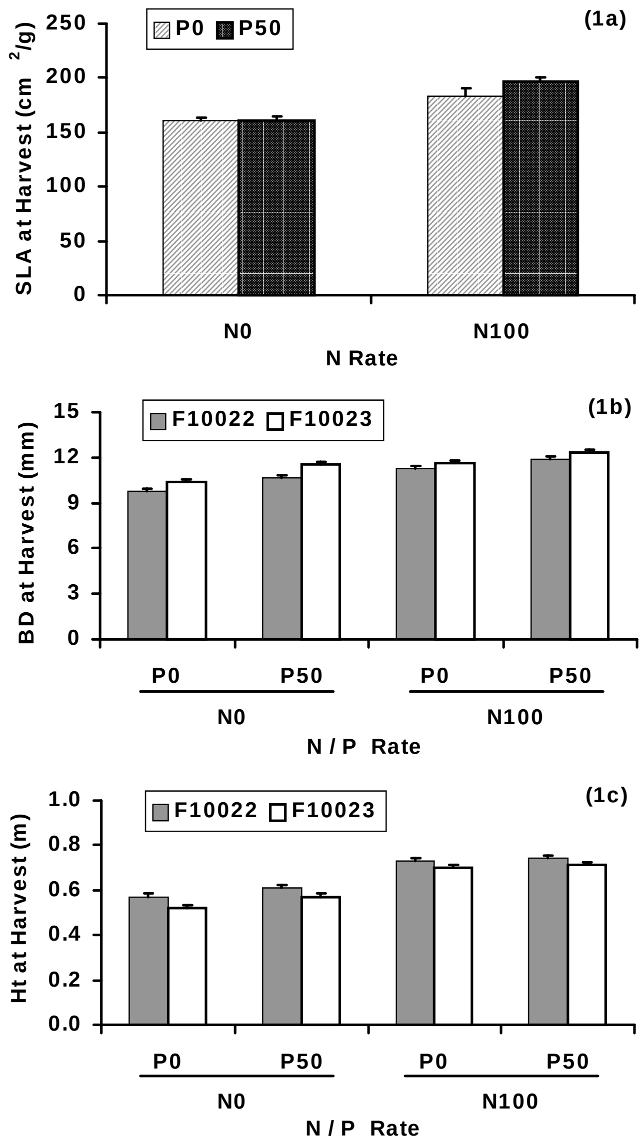

Figure 1—Mean + SE ($n = 4$) response of 2-year-old sweetgum to N and P application, and family (F10022 and F10023), by specific leaf area (SLA), seedling basal diameter (BD) and height (Ht), two months after treatment. figure 1a shows the interaction between N and P ($P < 0.05$) treatments on SLA when family was not significant. In figure 1b, N ($P < 0.10$), P ($P < .0.05$) and family ($P < 0.05$) were significant; and in figure 1c, N and family ($P < 0.05$) were significant.

sweetgum response to resource availability (Hopper and others 1992, Lockaby and others 1997, Nelson and Switzer 1990, 1992, Nelson and others 1995a).

Physiological responses to nutrient additions often appear first in foliar characteristics and crown expansion. Crown width in the current study was significantly correlated with initial seedling height ($P < 0.05$), and was affected by N ($P < 0.01$) and P ($P < 0.01$) additions (figure 2a). Differences in crown width between the families were not significant, nor were there any significant treatment

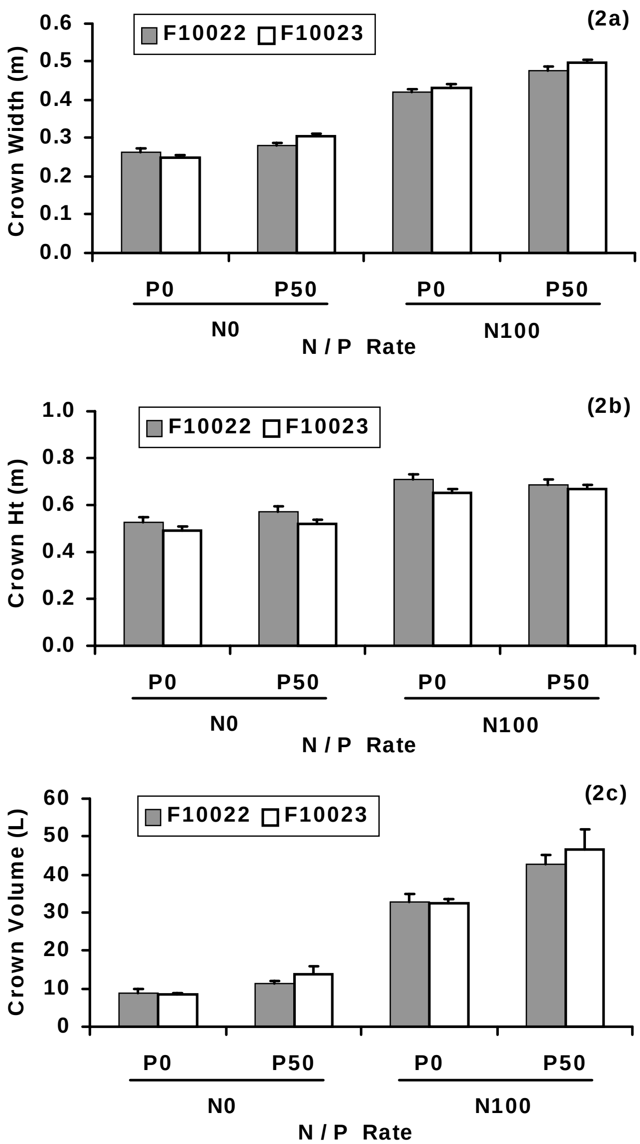

Figure 2—Mean + SE (n = 4) response of 2-year-old sweetgum to N and P application, and family (F10022 and F10023), by crown width, crown height and crown volume, two months after treatment. In figure 2a, N and P were significant ($P < 0.05$); in figure 2b, N and family were significant ($P < 0.05$); and in figure 2c, N and P were significant ($P < 0.05$).

interactions. Crown height was significantly correlated with initial SLA ($P < 0.05$), and was affected by family ($P < 0.05$) and N ($P < 0.01$) application (figure 2b). For crown height (similar to total height, figure 1c), family 10022 was greater than family 10023. When crown width and height were integrated into crown volume, family differences were not significant (figure 2c), although N and P additions increased crown volume. No interaction between N and P was found.

The significant effects of the N and P treatments on crown volume (Fig 2c) and SLA (Fig 1a) may be responsible, through their relationship with photosynthetic area, for the seedling growth responses found. With respect to basal diameter, N, P and family explained 37, 21 and 10 percent of the growth response, respectively.

CONCLUSIONS

N and P application affected the growth rate of two-year-old sweetgum seedlings, two months after treatment. Two half-sib families responded to the N and P treatments differently, indicating significant genotype x fertility variation in sweetgum. Thus it may be possible to select genotypes that are more efficient in nutrient use. Results suggest the need to balance N and P applications to seedling sweetgum, and that N generally limits the response to P.

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REFERENCES

Birks, P.J; Robison, D.J. 2000. Sweetgum family seedling screening and response to stress. In: Proceedings 25th Biennial Southern Forest Tree Improvement Conf; 1999 11-14; New Orleans, LA. Southern Forest Tree Improvement Comm., sponsored pub. No. 47: 36-39.

Hopper, G.M.; Buckner, E.R.; Mullins, J.A. 1992. Effects of weed control and fertilization on plantation establishment and growth of green ash, sweetgum, and loblolly pine: four-year results. In: Brissette, J.C., ed. Proceedings of the Seventh biennial southern silvicultural research conference; 1992 November 17-19, Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 357-360.

Kormanik, P.P. 1990. Sweetgum. In: Burns, R.M. and Honkala, B.H. (Tech. Coords.). Silvics of North America: 2. Hardwoods. USDA For. Serv., Wash., D.C. Agric.Handb. 654. Washington, D.C: U.S. Department of Agriculture. 400-405.

Lockaby, B.G.; Clawson, R.G.; Baker, T. 1997. Response of three hardwood species to irrigation and fertilization on an upland site. Southern Journal of Applied Forestry. 21: 123-129.

Meyer, D.A. 1996. Research priorities for North American hardwoods. In: Proceedings of the Twenty-Fourth Annual Hardwood Symposium, Putting Research to Work for the Hardwood Industry: New Technology Available Today; 1996 May 8-11; Cashiers, NC; 15-25.

Meziane, D.; Shipley, B. 1999. Interacting determinants of specific leaf area in 22 herbaceous species: effects of irradiance and nutrient availability. Plant Cell Environ. 22: 447-459.

Nelson, L.E.; Shelton, M.G.; Switzer, G.L. 1995a. Aboveground net primary productivity and nutrient content of fertilized plantation sweetgum. Soil Science Society of America Journal. 59: 925-932.

Nelson, L.E.; Shelton, M.G.; Switzer, G.L. 1995b. The influence of nitrogen applications on the resorption of foliar nutrients in sweetgum. Canadian Journal of Forestry Research. 25: 298-306.

Nelson, L.E.; Switzer, G.L. 1990. Sweetgum half-sib seed source response to nitrogen and phosphorus fertilization in Mississippi. Soil Science Society of America Journal. 54: 871-878.

Nelson L.E.; Switzer, G.L. 1992. Response of nine-year-old plantation sweetgum to nitrogen fertilization in Mississippi. Southern Journal of Applied Forestry. 16: 146-150.

Robison, D.J.; Goldfarb, B.; Li, B. 1999. Advancing hardwood production forestry. PaperAge. May, 22-24.

Walters, M.B.; Reich, P.B. 1996. Are shade tolerance, survival, and growth linked? Low light and nitrogen effects on hardwood seedlings. Ecology, 77: 841-853.